NEW ZEALAND.—MARINE DEPARTMENT.

FISHERIES BULLETIN No. 8.

NATURAL REPRODUCTION OF TROUT IN NEW ZEALAND AND ITS RELATION TO DENSITY OF POPULATIONS.

BY

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WELLINGTON:
E. V. PAUL, GOVERNMENT PRINTER.
—
1940.

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CONTENTS.

PAGE

INTRODUCTION 7

METHODS AND TECHNIQUE—
Mode of Collecting and System of Sampling 7
Material collected 8
Treatment of Material 8
Presentation of Data 9

THE NORTH OTAGO DISTRICT—
The Kakanui System 10

THE SOUTHLAND AND SOUTH OTAGO DISTRICTS 11
The Waiau System 12
The Aparima System 15
The Oreti System 16
The Waituna System 18
The Mataura System 19
Summary of Data for Southland and Otago Districts 22

THE AUCKLAND DISTRICT 23
The Waihou (or Thames) System 24
The Waikato System 27
The Awakino System 32
The Wanganui System 33
Summary of Data for Auckland District 33

SUMMARY AND DISCUSSION OF NEW ZEALAND DATA—
A. Quantitative Studies 34
B. Qualitative Data 34

LIMITATIONS OF MATERIAL AND POSSIBILITIES OF ERROR—
1. Sampling 40
2. Collecting 40
3. Efficiency of Deposition 41
4. Emergence of Fry 41
5. Estimations of Loss 42
6. Removal of Specimens from Redds—
A. By Flood Action 44
B. By Superimposition 49

THE SIGNIFICANCE OF SUPERIMPOSITION—
1. The Occurrence of Superimposition 56
2. Natural Regulation of Populations 57
3. Natural Regulation of Population of Trout 58
4. Exploitable Excesses of Natural Populations 62
5. Populations under Control 64

CONCLUSIONS 67

SUMMARY 68

ACKNOWLEDGMENTS 69

REFERENCES 70

APPENDICES 71

Fig. 1.—Hawaiian, in black, portions of New Zealand where streams were examined for present study and, cross-hatched, the area studied previously (see Hobbs, 1937).

NATURAL REPRODUCTION

OF TROUT IN NEW ZEALAND

AND ITS RELATION TO DENSITY OF POPULATIONS.

INTRODUCTION.

An earlier paper (Hobbs, 1937) dealt with the manner of spawning and efficiency of natural reproduction of quinnat salmon (*Oncorhynchus tschawytscha*), brown trout (*Salmo trutta* Linn.), and rainbow trout (*S. irideus*) in certain New Zealand waters. Observations were made then in a cross-section of the South Island. The present paper covers observations on trout of both species made over a much wider field — the Otago and Southland Districts, in the southern portion of the South Island, and the Auckland District, in the northern half of the North Island. New areas in which observations have been made are shown in black in Fig. 1. The cross-hatched section is that covered by former observations. The object of the present work was to establish how general an application conclusions drawn from earlier observations had.

METHODS AND TECHNIQUE.

MODE OF COLLECTING AND SYSTEM OF SAMPLING.

The methods and technique described in the earlier paper were followed except in so far as modifications are recorded. Previously the aims were to obtain samples of ova and larval fish from sample series of spawning redds, to employ a standard method of describing degrees of development, and to show the extent of losses to successive points of development. Here each sample obtained (except some taken inadvertently from contiguous redds) results from a reasonable attempt, though not necessarily a completely successful one, to recover the total contents of one redd.

For the collection of samples a net of cotton mesh, having sixteen apertures to the linear inch, was used. It had a forward rectangular opening of 4 ft. by $1\frac{1}{2}$ ft., and tapered in a length of 5 ft. to a tube 3 in. in diameter and 6 in. long. A piece of chain of $\frac{1}{2}$ lb. weight per foot was inserted in the lower seam of the forward opening. The sides of the net at the forward end were secured by loops to two light steel rods which were driven into the stream-bed. The terminal opening was secured by a cord. The net was set below redds at such a distance that specimens would drift into it while the heavier material would not.

The intention of making collections from representative areas of the principal types of spawning environment in New Zealand was substantially fulfilled. The amounts of material collected from different areas do not bear a uniform relationship to the quantities available for collection in such areas. Generally, however, the larger collections are from more important spawning-areas than are the smaller. Exceptions occur principally where flood conditions in larger rivers restricted work to smaller waters. As regards any one water-system, endeavours were made to collect from many different points and to take from them large or small numbers of samples, according as redds were plentiful or few.

MATERIAL COLLECTED.

Collections were made in the years 1935–37. Earlier (Hobbs, 1937) it was shown that the most vulnerable stage of development in natural redds is before the eyes become pigmented in the ova. As far as possible, districts were visited at times which permitted of the collection of material which had completed pre-eyed development. Thus it was necessary to work first in the North Island, where milder conditions made for more rapid development, then in the coastal areas of the South Island, and finally to extend back into the southern ranges, where spawning was later and development slower.

Material, comprising in all 427,715 specimens of ova and larval fish, was collected from 541 redds in 64 streams comprising portions of 10 river-systems. In the Auckland District 101,303 specimens were taken from 137 redds of both brown and rainbow trout in 22 streams comprising parts of 4 systems. In North Otago 45,258 specimens were obtained from 62 redds of brown trout in 2 streams comprising 1 system. In Southland and South Otago 281,164 specimens were taken from 342 redds, predominantly of brown trout, but possibly including some of rainbow trout and Atlantic salmon, in 40 streams comprising parts of 5 systems.

TREATMENT OF MATERIAL.

Where, in collecting a sample from what appeared at first to be only one redd, material was also obtained from other redds, the mixed material was sorted, where possible. Where only live specimens and some of the dead could be distinguished with certainty, older dead specimens were apportioned in the proportion of the distinguishable dead. In a few cases, comparative uniformity of egg size, colour, and point of development made sorting impossible. In such cases two or more index numbers (according to the number of samples the mixture is believed to represent) are shown against the analyses made in the tables. Such unsorted lots are credited with the average point of development attained by the live specimens. Except where indicated as above, each sample of specimens is believed to be the product of one female. It has been shown previously (Hobbs, 1937) that a trout commonly makes more than one redd in a spawning season. There is therefore reason to believe that each of the majority of samples obtained constitutes a major part of the contents of one of several redds a female may have made.

Samples are divided into three main categories, according as the majority of specimens in any consisted predominantly (1) of eggs in which the eyes were not pigmented, (2) of eggs in which the eyes were pigmented, or (3) of larval fish (alevins). From ten live specimens in each sample of ova there was determined the average ratio of embryo length to egg diameter. From ten live specimens of each sample of alevins there was determined the percentage wet weight of embryos to larvæ—*i.e.*, of larval bodies to bodies plus attached yolk. In the tables, material is listed in three successive groups of development and the point of development inside each group is also shown. Dead specimens are listed according as they had died as pre-eyed or eyed ova, or as alevins. In cases (more particularly in advanced alevin samples) where some of the dead ova were so decomposed as to make accurate appropriation to either category impossible, such ova are included with pre-eyed dead. It seems reasonable to suppose that

those which had died earliest would normally have decomposed most. The possibilities of dead ova and alevins having decomposed to stages which would not permit of their recovery by the methods employed are considered later. All material collected is included, with the exception (*a*) of a few samples taken so shortly after deposition that their incorporation would serve no useful purpose, (*b*) of thirty-four samples of less than fifty specimens each taken inadvertently from redds contiguous to those being dug, and (*c*) of chorions of eggs crushed while being dug out, which were discarded for reasons given earlier (Hobbs, 1937).

PRESENTATION OF DATA.

Different districts are treated separately, and, within each, data are presented and discussed in regard to separate water-systems. Where data are sufficient for such a purpose, they are subdivided to show conditions in different portions of water-systems. Minor collections, having only a limited indicative value, are grouped under their respective water-systems, and samples comprising each are distinguished in tables by the addition to their index numbers of the initial letters or syllables of their streams of origin.

Where collections are from spawning-streams significant enough to justify the practice, a brief tabular form of stream description is employed. Where such descriptions are given, lengths of rivers and of sampling areas are approximations only, obtained by using a rotameter on maps with a four-miles-to-the-inch scale. Descriptions of streams indicate their general character in sampling-areas, rather than the character of the restricted portions of such areas used by spawning fish. The term "flood-bed" is applied to such portion of the area over which flood-waters pass as normally has an eroded surface and a deficient covering of vegetation. Descriptions of material comprising beds of streams relate to the dominant material: in all cases it should be understood that finer materials are also present.

Only introduced Salmonidæ are noted in descriptions of stocks. In New Zealand the composition of stocks varies greatly in different waters and often in different seasons in the same water. Some stocks show little change in the proportions of small to large fish throughout the year. Others are essentially nursery streams, holding little above yearling size in summer and being occupied almost exclusively by spawners in winter. Others show a temporary replacement of several immature year classes by spawners for a few weeks only. Again, some (and they are often large streams) are occupied almost exclusively by spawners in winter and in summer contain fish of less than a year old with a sprinkling of large mature fish, trout of intermediate size being absent. Where knowledge is extensive enough, the nature of the stock is briefly indicated.

The years and months of collection of samples are given. Also, there is shown the number of cases where overlapping of redds occurred, so that the excavations of two or more occupied the same space. Such overlapping and overlapped redds are shown, as a proportion of the total redds sampled, against the heading "Proportion Contiguous."

In the case of each water-system, data relating to the nature of streams, their stocks, and spawning-areas, together with particulars of individual samples collected, are given in an Appendix.

THE NORTH OTAGO DISTRICT.

THE KAKANUI SYSTEM.

The Kakanui River is one of a series of streams draining eastwards into the South Pacific Ocean from the Southern Alps. In common with many others, it has, after leaving the hills, a bed of gravel and boulders of a hard sedimentary rock (greywacke). It resembles many of the more stable of the streams on the extensive flood-plains of Canterbury, north from it. The Oreti River, of Southland, described later, has much in common with the less stable of such rivers with beds which are aggrading (building up). Precedence is given here to the Kakanui system not because it has any special significance as an angling stream, but because collections from it are more extensive than those from other waters.

A description of relevant features of the Kakanui system is given in Appendix A. Details are shown there, in Table 1, of samples collected from redds of brown trout.

DISCUSSION.

Losses among specimens recovered from redds in the Kakanui are given in the following summary :—

Of 10,388 specimens in 16 pre-eyed samples, dead pre-eyed ova = 228, or 2·19 per cent.

Of 17,477 specimens in 28 eyed samples, dead pre-eyed ova = 532, or 3·04 per cent. ; and dead eyed ova = 19, or 0·11 per cent.

Of 17,383 specimens in 18 alevin samples, dead pre-eyed ova = 471, or 2·71 per cent. ; dead eyed ova = 53, or 0·30 per cent. ; and dead alevins = 30, or 0·17 per cent.

Although the position is otherwise here, the exigencies of sampling sometimes result in a heavier pre-eyed loss being shown by the alevin samples than by the eyed-ova samples. A uniform practice is therefore employed of computing the pre-eyed loss from the data afforded by both eyed-ova and alevin samples. The loss in the eyed stage is then computed on the assumption that it would bear the same ratio to the computed pre-eyed loss as is found in the alevin samples. The possibilities of error in computing losses are discussed in a subsequent section. It is not claimed for the practice adopted that it will give entirely accurate results. The practice is expedient ; errors consequent on its adoption are likely to be less than those attributable to the exigencies of sampling, and it gives a result at least approximate enough for such practical purposes as this paper serves.

The 34,860 specimens from the two categories of samples which have completed pre-eyed development show a pre-eyed loss of 1,003, or 2·88 per cent. If, as shown by alevin samples, there is, with a pre-eyed loss of 2·71 per cent. an eyed-stage loss of 0·30 per cent., then on this basis, with a pre-eyed loss of 2·88 per cent., there would be an eyed-stage loss of 0·32 per cent. Thus a total loss before hatching of 3·20 per cent. is shown. A very low subsequent loss, as alevins before emergence as fry, is indicated. In a range of samples embracing successive degrees of larval development only 0·17 per cent. were dead. In the case of a few of the more advanced alevin samples, in this and other collections, fry were emerging at the time of sampling, and therefore dead specimens may have been residual from a number of specimens greater than that recovered.

Silting to an extent harmful to the contents of redds rarely occurs in the Kakanui. In all save five of sixty-two samples, dead recovered amounted to less than 10 per cent. In these five cases the silt content of the redds, judged by the degree of turbidity consequent on disturbance, was abnormally high. In the case of Sample 33, this appeared to be attributable to the construction of another redd immediately in front. Of some hundreds of redds seen in the Kakanui in three years, two only were observed to be affected adversely by conditions not noticed in the case of any of the sixty-two redds sampled. In one case a redd constructed during a fresh was left, after subsidence of flood-waters, in stagnant water. All the eggs in it were dead. The other redd was in the lower portion of the Kauroo. This stream maintains a permanent flow in its hill section and an impermanent one in its lower reaches, where there is a broad bed of loose shingle. This redd had been constructed during the temporary passage of water through the lower area and was subsequently left by receding water. When found, it was dry down to the level at which eggs had been buried. The absence of live specimens and the small number of dead in it suggested that fry might have escaped earlier. In a previous paper it was shown that eggs may develop without abnormal loss when left above water-level in damp material in redds (Hobbs, 1937).

THE SOUTHLAND AND SOUTH OTAGO DISTRICTS.

Four major water-systems drain the occupied country of Southland in a generally southerly direction and enter the South Pacific Ocean in the vicinity of Foveaux Strait. From the west, these are the Waiau, Aparima, Oreti, and Mataura. The Mataura system also drains a portion of South Otago. The streams comprising these water-systems include some of the most productive trout waters of New Zealand. It is unlikely that any other portion of the country of a like extent to that drained by them affords brown-trout fishing of an equal standard. Rainbow trout and Atlantic salmon occur also in portions of the Waiau system. Apart from the Aparima and Oreti, the streams entering the sea between the mouths of the Waiau and Mataura are of very small size and of little importance. They are the Waimatuku, Waikiwi, Waihopai, and Waituna. Of these, the last three are similar in character.

The Waiau drainage area marks the eastern limit of the heavy-rainfall and heavily timbered country in Southland. The Waiau flow is largely lake-controlled, and below the lakes its course is in a comparatively narrow valley. To the east the mountain country drained by the Aparima, Oreti, and Mataura is mainly tussock clad with light timber on shaded aspects. The Aparima and Oreti, once they leave the foothills, have braided channels in wide flood-beds through broad flood-plains. The Mataura shows less tendency to spew out into many channels than do the Aparima and Oreti, but is less confined than the Waiau. The smaller intermediate coastal streams have short courses through low-lying deforested country.

To a considerable extent conditions which determine the accessibility of these various waters to anglers determined their accessibility to the writer. Thus, in the Waiau system the accessible major tributaries entering from the east were especially studied. Examinations of the Aparima and Oreti were more extensive than those elsewhere. In waters

of the Mataura system, turbidity resulting from gold-mining operations limited work to the upper reaches of the principal stream and to certain tributaries.

While, in many respects, it is convenient to group for consideration the streams comprising one water-system, such a practice would mislead if it suggested that there was always greater uniformity of conditions within one system than between parts of one and parts of another. For instance, the important Makarewa sub-system of the Oreti has more in common with Waituna Creek than with its principal stream.

The courses of Southland streams are shown in Fig. 2. In this are given the approximate positions where samples were collected, places where no evidence of reproduction was obtained, and localities where reproduction occurs but no samples were taken.

THE WAIAU SYSTEM.

The Waiau River drains Lake Te Anau, which is some forty-three miles long. The western tributaries of the lake were not examined. They are not known as angling waters, and are reported to follow precipitous courses, offering very limited facilities for the spawning of trout. Two large rivers, the Eglinton and Upukerora, and a small stream, Henry Creek, drain from the east into Te Anau. A sixteen-mile reach of the Waiau links Te Anau with Lake Manapouri, below which the river has a length of about sixty-one miles. The Mararoa enters from the east shortly below Manapouri; and twenty-four miles from the Waiau mouth the Wairaki enters from the same side. The Eglinton, Upukerora, Mararoa, and Wairaki are large streams, possessing, over considerable distances, beds of rather unstable greywacke boulders and gravel. Lakes in the courses of the Eglinton and Mararoa add to the stability of the upper portions of their beds. The Orawia sub-system enters from the east some miles below the Wairaki. The streams comprising it are the most stable and, faunistically, the richest in the Waiau system.

The salmonid stock of the Waiau system is predominantly a brown trout one. Rainbow trout and Atlantic salmon, which also occur, are largely restricted in their range to the upper portion of the principal stream and to tributaries of Lake Te Anau. Material from this system is presented in Table II, Appendix B, in seven series. Each of six represents a tributary or sub-system important enough to warrant separate consideration. The other comprises material from four minor streams, of which three, the Retford and Henry Creeks and Holly Burn, are similar in character.

Discussion of Redds in Streams of Waiau System.

Waiau River.

The principal stream is described in more detail in Appendix B. Material collected from it comprises Series A of Table II in this Appendix.

The only heavy loss is in Sample 9, in which debris had settled during the construction of a contiguous redd. This redd was in marginal waters in the reach between the two lakes, where considerable overlapping of redds occurs.

Eglinton and Upukerora Rivers.

The chief features of these two tributaries of Lake Te Anau are noted in Appendix B, where material from them comprises Series B and C respectively of Table II.

An unusually high proportion of the redds in the Eglinton and Upukerora showed heavy losses—10 per cent. was exceeded in twelve of the twenty-six samples. An examination of eggs in the principal Te Anau hatchery, stripped from trout in these streams, was made on 12th August, 1935. A fair sample showed a 9·2 per cent. infertility loss in trays from which many dead had already been picked out. Locally it is stated that there are greater difficulties in the fertilization of eggs from these waters than from others. Comparative data are lacking. The possibility of a proportion of the eggs being inherently defective is noted, however.

The spawning fish in the Waiau system are of much greater average size than those of most other streams examined. Their redds are also of greater average size. Many are from 7 ft. to 15 ft. long. Usually ova are buried in them at a depth of 9 in. to 14 in. Abnormalities were noted in the case of nine of the twelve redds which showed losses in excess of 10 per cent. The 226 specimens comprising Sample 21, Series B, were remnants from the superimposition of a later redd. Another small sample, 23, in the same series came from an unusually shallow redd in coarse and abnormally cemented material. The ova had not been buried at a sufficient depth to stop silt penetrating to them. Samples 30 and 36, Series C, came from an unusual medium—predominantly coarse grit and sand with little heavier material. Samples 14 and 17, Series B, and 32, Series C, came from redds of 8½ ft. to 14 ft. in length. Dead were recovered almost exclusively from pockets at the down-stream ends of these redds. The earlier eggs deposited may have been more vulnerable, but such a finding would be inconsistent with general findings. It seems possible that losses resulted from the reduction of oxygen content in the water by the time it had passed through the live eggs farther up-stream. In five other samples losses ranged from 10·2 per cent. to 21·1 per cent. In two of these cases the contours of the redds had been substantially modified and the silt content increased by the construction of contiguous redds. In the remaining cases the samples were large, 1,705, 1,141, and 3,821 specimens respectively, but it was not noted whether or not dead came mainly from any especial portions of the redds.

Mararoa River.

The principal features of this stream are noted in Appendix B, where details of samples collected are shown in Series D of Table II.

The losses, except in Sample 37, are low. In this case 740 of the dead, or 30 per cent. of the total, were infertile eggs which still retained their osmotic equilibrium. Its retention until live ova have hatched is not remarkable. This is one of the very few redds encountered with a high infertility loss.

Wairaki River.

Material from this water is shown as Series E of Table II, in Appendix B, where the stream is also described.

Losses exceeded 10 per cent. in three of nine samples. No. 46, with a loss of 57·4 per cent., was from a small, shallow, dirty, trial redd which had been adversely affected by superimposition. No abnormal conditions were noted in the case of Sample 49, where the loss was 14·7 per cent. Sample 50—loss, 18·1 per cent.—was dirtier than most.

Orawia (Orauea) Sub-system.

Portions of this sub-system are described in Appendix B, where material collected is shown in detail as Series F of Table II. The initial letters of different branches are used in the index to denote the origin of samples, except that the letter "M" is used to indicate material from both the Morley and Ohai.

Of the thirty-two samples, six show losses of over 10 per cent. In all six cases the silt content was excessive. This condition had in three cases been either caused or aggravated by the construction of contiguous redds immediately in front of these samples.

Sundry Minor Tributaries.

From the Retford and Henry Creeks, the Monowai River, and Holly Burn, two, one, one, and five samples respectively were taken. The Retford is a tributary of the Eglinton River, the Monowai drains the lake of that name, Henry Creek enters Lake Te Anau, and the Holly Burn enters the lagoon at the Waiau mouth. The three latter are small, fairly stable streams of moderate gradient. The two latter flow through bush country. Data relating to collections made in these four streams are shown as Series G in Table II.

Of nine samples, four showed losses in excess of 10 per cent. One redd in the Retford with a 27·4 per cent. loss was unusually shallow. The redd was clean. A sheep-track crossed it. It seems likely that burial was insufficient to safeguard the eggs from concussion when at their most sensitive stage. In the other three cases the redds were unusually dirty. Two samples showed very abnormal features. Osmotic equilibrium of dead fertilized eggs was maintained in one case in 15·1 per cent. and in the other in 36·1 per cent. of the dead specimens recovered. These dead included eyed and pre-eyed eggs. Hobbs (1937) gave an earlier instance of such an occurrence. In the present collections the maintenance of osmotic equilibrium after death was noted in the case of a few specimens in a number of samples. The same two samples were also remarkable for the great variety of points of development represented by the material comprising them. It is usual for slight differences to be shown even in samples from single-pocket redds and for wider differences to occur in some redds with several egg-pockets. In one of the two present samples, however, live eggs of approximately the same size and believed to be the product of one fish deposited at about the same time contained embryos, some of which were only half the size of others. It appeared likely that development at differentiated rates had taken place. The only abnormal accompanying condition noticed was a silt content sufficient to suggest that some of the eggs might have suffered from a deficiency of oxygen.

Summary of Waiau System Data.

In all, 114,214 specimens were collected from ninety-one redds in streams comprising the Waiau system. The average number of specimens collected per redd, 1,255, is the highest for any of the ten water-systems. The average size of fish at first maturity is unusually high in the Waiau system.

Of 15,213 specimens in 18 pre-eyed samples, dead pre-eyed ova = 948, or 6·23 per cent.

Of 56,708 specimens in 38 eyed samples, dead pre-eyed ova = 5,384, or 9·49 per cent.; and dead eyed ova = 1,131, or 2·01 per cent.

Of 42,293 specimens in 35 alevin samples, dead pre-eyed ova = 3,605, or 8·53 per cent.; dead eyed ova = 919, or 2·17 per cent.; and dead alevins = 78, or 0·18 per cent.

Of 99,001 specimens which had completed pre-eyed development, dead pre-eyed ova numbered 8,989, or 9·07 per cent. Estimated on the basis of an eyed-stage loss of 2·17 per cent. with a pre-eyed loss of 8·53 per cent. (both shown by alevin sample material), the eyed-stage loss would be 2·31 per cent., when the pre-eyed loss is 9·07 per cent. This basis of estimation gives a loss of 9·07 + 2·31 per cent. = 11·38 per cent. before hatching.

THE APARIMA SYSTEM.

The Aparima collects the eastern drainage of the Takitimo Mountains and of the Longwood Range. Three groups of tributaries—those comprising the Hamilton Burn, Otautau, and Pourakino sub-systems—do not appear to have any major significance as nursery streams. The principal stream was not examined above the bridge on the Wrey's Bush – Mossburn Road during the spawning-season. It is known that trout spawn above this point.

The Aparima is more fully described in Appendix C. Details of material collected from the main stream and tributaries are given there in Table III, where Series B comprises material from the following tributaries: Pourakino, Otautau, Etal, and Hamilton. The place of collecting is indicated by the use of the appropriate initial letter.

Discussion.

In eight of the forty-three samples losses exceeded 10 per cent. No. 23, with a loss of 14·3 per cent., came from a redd from which the current had been diverted as the stream fell to a lower level. In Sample 8, much of the loss of 63·7 per cent. seemed attributable to the excessive amount of fine material present. The material had been dislodged from immediately in front during the construction of another redd. Of the 33 per cent. loss in Sample 21, infertile eggs accounted for 28 per cent., another of the rare cases of a heavy loss attributable to this cause. The bulk of the dead in Sample 16 were fertilized pre-eyed eggs in which osmotic equilibrium was maintained. Attendant conditions were normal; possibly the eggs were inherently defective. Of the remaining four samples, the two showing the heaviest losses were recovered during a fresh which made observation of attendant conditions impossible.

Summary of Aparima System Data.

Of 1,943 specimens in 6 pre-eyed samples, dead pre-eyed ova = 17, or 0·87 per cent.

Of 11,650 specimens in 13 pre-eyed samples, dead pre-eyed ova = 1,088, or 9·34 per cent.; and dead eyed ova = 38, or 0·33 per cent.

Of 21,770 specimens in 24 pre-eyed samples, dead pre-eyed ova = 1,009, or 4·67 per cent.; dead eyed ova = 94, or 0·43 per cent.; and dead alevins = 40, or 0·19 per cent.

The 33,420 specimens from samples which had completed pre-eyed development show a loss of 2,097, or 6·27 per cent. The accompanying eyed-stage loss, estimated on the basis of proportions of eyed to pre-eyed losses as shown by alevin samples, would be 0·58 per cent. This gives a loss of 6·85 per cent. before hatching occurs. A subsequent loss of small size is indicated.

THE ORETI SYSTEM.

The Oreti River rises in the Thomson Mountains and, as a small stream, flows down McKellar's Flat, a tussock-clad depression between the Thomson and Eyre Mountains. A narrow valley then confines it until, some ninety miles from its mouth, it emerges from the hills at Centre Hill and flows for a short distance through a broad valley floor and then across extensive flood-plains. The depth of the finer material overlying coarse alluvium increases towards the coast and poor tussock-clad land improves to land of high fertility. The Oreti is increased in size by the collection of the western drainage of the Eyre Mountains in its hill section, the southern drainage of the same ranges in the Five Rivers Plain, and the important Makarewa sub-system in its tidal reaches.

No winter examination was made of the McKellar's Flat reach, but in January, 1936, redds made the previous winter were still discernible there. The principal river was examined intermittently from Centre Hill to Lumsden, extensively from there to the entrance of Dipton Creek, and intermittently lower down. Through much of the length examined the river occupies a number of channels in a wide flood-bed between banks and islands of shingle growing gorse and broom on their higher and more stable portions.

Examinations of tributary waters, other than those comprising the Makarewa sub-system, were limited to their lower reaches. A relatively greater quantity of material was collected from a spring creek opposite Lumsden than from other parts of the system: this was because freshes frequently interfered with work elsewhere.

Spackman (1892) states: "Of all the rivers exclusively confined to the Southland District, the Oreti River takes the palm, being the most prolific of trout owing to its superiority as a trout-breeding stream."

Some idea of the fall per mile in different reaches can be obtained from the heights above sea-level of railway-stations on flats adjacent to the river. The following information is based on heights given in railway time-tables:—

Mossburn to Lumsden (13 miles): Fall, 332 ft. = 25·5 ft. per mile.
Lumsden to Dipton (14 miles): Fall, 204 ft. = 14·5 ft. per mile.
Dipton to Limehills (13 miles): Fall, 179 ft. = 13·8 ft. per mile.
Lime Hills to Winton (7 miles): Fall, 82 ft. = 11·7 ft. per mile.
Winton to tidal limits (25 miles): Fall, 164 ft. = 6·5 ft. per mile.

In any of these reaches greatly contrasting velocities occur. Redds were found in great abundance between Lumsden and Dipton and, but

rarely, above Lumsden. Some further description of the Oreti system will be found in Appendix D, where details are given of samples collected.

Material from the Oreti itself comprises Series A of Table IV. Series B comprises samples collected from the following tributaries: Centre Hill Creek, Flaxy (or Christies) Creek, Irthing River, Murray Creek, Spirit Burn, and Dipton Creek. The initial letters are used in the index to denote stream of origin. The Irthing and Dipton have beds of relatively unstable rounded greywacke. Centre Hill, Flaxy, and Murray Creeks have stable beds of thickly diatom-clad greywacke gravels with some growth of coarse bed-rooted vegetation. Spirit Burn has little significance as a nursery stream. Series C comprises material from a large spring creek of short course opposite Lumsden. This material is a mixture of samples from the stable portion of the creek and its lower, less stable, course, where it is in the Oreti flood-bed.

Discussion.

In only six of the eighty samples is a loss of over 10 per cent. shown. In three cases—namely, Samples 16, 58, and 75, with losses of 13·5 per cent., 29·1 per cent., and 12·5 per cent. respectively—silt had settled in the redds consequent on the subsequent construction of other redds immediately in front. Clods of clay, overlying the coarse alluvium of an eroded bank, had fallen on to the redd from which Sample 7 was taken. The small Sample 22, with 37·4 per cent. dead, came from a dirty redd, excavated to a depth of only 4 in., in a portion of the bed having a steep lateral incline. It is exceptional for a redd to be made in such a position. Sample 25, with a loss of 12·1 per cent., came from a redd in which one pocket was silted.

The Makarewa Sub-system.

The greater size and different character of the Makarewa sub-system warrants its separate treatment. The streams of this sub-system are, together with portions of the Orawia sub-system, Murray Creek, and the coastal streams exemplified by Waituna Creek, among the most stable in Southland. Unlike the Aparima, Oreti, and the less stable of the Waiau tributaries, which become fairly turbid during floods, the Makarewa waters and Waituna Creek show to some extent the brownness characteristic of peat streams.

The principal waters of the sub-system are the Makarewa, Lora, Otapiri, Dunsdale, Hedgehope, and Titipua. Together they form a stream some 20 ft. to 45 ft. wide and usually from $1\frac{1}{2}$ ft. to $4\frac{1}{2}$ ft. deep. The upper Makarewa, the Lora, Otapiri, and Dunsdale drain southwards out of the Hokonui Hills, in parts over bed-rock and in parts over resultant gravels. Material representing these waters comprises Series D2 in Table V, Appendix D. The Makarewa, below its junction with the Otapiri, and the Hedgehope and Titipua, which drain flats at the foot of the Hokonui Hills, follow extremely sinuous courses over beds which, in their more rapid portions, consist of quartz gravel. Banks are generally steep, stable, and vegetation-clad, and rise from 4 ft. to 16 ft. There is a moderate to prolific growth of rooted aquatic plants from the hills down to tidal water. Short gravelly bars divide pools and slow-flowing reaches. Hedgehope Railway-station is 150 ft. above sea-level and, via the Hedgehope and Makarewa Streams, is about forty miles from the tidal waters, into which the pool and gravel-bar type of bed persists. The presence throughout the sub-system of an abundance of maturing trout in late summer, and the

presence in spring of fry at many points between the hills and tidal waters, suggests more general spawning than the finding of redds indicated. Much of the gravel on the surface of the bed is embedded in finer matter and is avoided by spawners. Where a thin coating of uncemented gravel overlies more stable material, redds are made. In such places a slight fresh is often sufficient to level the mounds of redds. Most of the redds were found by prodding with a shovel for yielding material in the most suitable looking places in apparently undisturbed bed. Material from the quartz-gravel sections is shown in Series D1 of Table V.

Discussion.

In six of thirty-two cases losses exceeded 10 per cent. but were less than 20 per cent., with the exception of Sample 87, where the loss was 65·4 per cent. Another redd had been constructed on top of this, and specimens recovered were probably remnants of a larger quantity originally deposited. In three other cases, redds made subsequently overlapped those which yielded heavy loss samples. Sample 103 was made in unusually dirty medium. No. 105, with an 18·6 per cent. loss, may have contained remnant dead from a contiguous redd from which fry had emerged. The sample was collected during a fresh, and attendant conditions could not be properly determined. The Hedgehope samples in Series D1 came from redds with exceptionally dirty surface areas but in which silt had not penetrated in quantity to the egg pockets.

Summary of Oreti System Data.

The material comprises eighty samples from the Oreti and its smaller tributaries and thirty-two samples from the waters of the Makarewa subsystem :—

Of 8,476 specimens in 20 pre-eyed samples, dead pre-eyed ova = 143, or 1·69 per cent.

Of 33,433 specimens in 50 eyed samples, dead pre-eyed ova = 1,190, or 3·56 per cent. ; and dead eyed ova = 278, or 0·83 per cent.

Of 31,895 specimens in 42 alevin samples, dead pre-eyed ova = 978, or 3·07 per cent. ; dead eyed ova = 390, or 1·22 per cent. ; and dead alevins = 32, or 0·10 per cent.

The 65,328 specimens in eyed and alevin samples show a loss of 2,168, or 3·32 per cent., as pre-eyed ova. The loss as eyed ova, estimated on the same basis as hitherto, is 1·32 per cent. Thus a loss of 4·64 per cent. before hatching is shown. Subsequent losses of larval fish are, as usual, very low.

THE WAITUNA SYSTEM.

Waituna Creek is one of a series draining low-lying coastal country between the mouths of the Oreti and Mataura Rivers. All of them are fairly slow flowing, brown-watered streams, with weed-grown beds broken by short reaches of quartz gravel. In all cases gravel-bars occur down to tidal waters. The courses of these streams are through country of a similar character to that traversed by the Makarewa system waters below their hill sections. The streams have cut through lighter materials overlying old alluvial quartz gravels.

Waituna Creek is the largest of three small streams entering the brackish Waituna Lagoon. Among Southland streams, the creek is remarkable

both for the size of the spawning-run which enters it and also because, being essentially a nursery stream, it offers no angling. Angling is limited almost entirely to the tide-rip at the outlet of the lagoon, where trout of less than 3 lb. are rarely taken.

Further particulars of Waituna Creek are set out in Appendix E, where, in Table VI, details are given of samples collected.

Discussion.

The table includes two samples which could not be satisfactorily separated. In eighteen of twenty-eight samples, dead exceeded 10 per cent., and in ten of the eighteen were in excess of 20 per cent. Losses are unusually heavy. They reflect unsatisfactory features of the spawning medium. Rounded quartz gravel, the product of earlier fluviatile action, occurs at varying distances beneath the surface of the whole Waituna drainage area. Waituna Creek has cut through the finer material—largely clay—overlying ridges in the gravel, but it has lacked the force necessary to make any considerable impression on the more resistant gravel. Clay and swamp detritus are in the gravel in excessive quantities. Inimical conditions have been aggravated by the massing of redds, i.e. material disturbed by late spawners had frequently settled in redds immediately below. Redds constructed in rapid water have long low mounds; in slacker water they rise to a greater height in a shorter distance. Redds in Waituna Creek were of the latter type. Frequently the upstream faces of the mounds had concave contours instead of the more usual convex ones. Redds rose sufficiently steeply from the bed to impede the flow of water considerably. At one point, where the stream was 9 ft. 6 in. wide, a group of redds reached from bank to bank. The disturbed portion of bed rose fairly uniformly from a depth of 22 in. to within 6 in. of the surface in a distance of 5 ft. 1 in. From the peak it fell again to 21 in. in a distance downstream of 11 in. The deposition of eggs per average square inch was 0·546. Eggs believed to be part of the product of six females were recovered from this plot.

Summary of Waituna System Data.

Of 1,066 specimens in 3 pre-eyed samples, dead pre-eyed ova = 31, or 2·91 per cent.

Of 12,792 specimens in 19 eyed samples, dead pre-eyed ova = 2,925, or 22·87 per cent.; and dead eyed ova = 1,003, or 7·84 per cent.

Of 1,585 specimens in 6 alevin samples, dead pre-eyed ova = 183, or 11·55 per cent.; dead eyed ova = 65, or 4·10 per cent.; and dead alevins = 1, or 0·06 per cent.

Of the 14,377 specimens in eyed and alevin samples, 3,108, or 21·62 per cent., died in the pre-eyed stage. A pre-eyed loss of 11·55 per cent. is associated with an eyed loss of 4·10 per cent. in the alevin samples. Estimated on this basis there would, with a pre-eyed loss of 21·62 per cent., be an eyed loss of 7·67 per cent., bringing the loss before hatching to 29·29 per cent. As in other cases, the alevin data indicates that once hatching-point is passed there is little danger of heavy loss.

THE MATAURA SYSTEM.

The Mataura River rises in the south-eastern face of the Eyre Mountains, and flows through a narrow alluvial flat between these ranges and the Garvie Mountains before cutting through the south-western end of the latter ranges

to emerge into a flood-plain. The Mataura in the upper reaches drains schist country and, in the flood-plain, encounters greywacke gravels and, later, quartz and greywacke gravels. The major tributary system—the Whakaea—collects the eastern drainage from the schist bed-rock of the Garvie Mountains. The Tomogalak brings in western drainage over a greywacke bed. Lower down, on the same side, the Otamita, after flowing largely over bed-rock in the Hokonui Hills, enters in the flood-plain section. The lower portions of the beds of the eastern tributaries—the Waikaka, Mairarua, and Mimihau—consist largely of quartz gravels.

The entrance of gold-mining debris keeps turbid the lower one hundred and thirteen miles of the Mataura, fifteen miles of the Whakaea, and eight miles or so of the Waikaka. Angling of a very high order is afforded by the first two streams during temporary cessations of sluicing. Spawning-areas located in the upper and clear-water portion of the Mataura were not extensive enough to suggest that they were used by any considerable part of the turbid-water stock in addition to the local stock. Spawning fish enter the Mimihau in considerable numbers. Nothing, however, is known of the spawning habits of the trout which occupy the eighty miles of turbid water of the principal stream between the entrance of the Nokomai River and that of the Mimihau. The bed of this part is of gravel. Tributaries, other than those comprising the Whakaea sub-system, are of small size and limited significance as nursery areas. Of them the Waimea and Otamita are best known as angling waters. It seems more likely that the stocks of these two streams are maintained, in part, by migration from the principal stream than that they make a significant contribution to its stock.

Collections from the main stream came from the twenty-three miles of water between Fairlight and the entrance of the Nokomai River, where pollution by mining debris commences. Railway data are the basis of the following statement of approximate falls in different lengths of the Mataura :—

Source to Fairlight (14 miles) : — ft. per mile.
Fairlight to Garston (5 miles) : 13·6 ft. per mile.
Garston to Athol (9 miles) : 12·0 ft. per mile.
Athol to Parawa (5 miles) : 7·2 ft. per mile.
Parawa to Gore (66 miles) : 9·5 ft. per mile.
Gore to sea (52 miles) : 4·5 ft. per mile.

Above Fairlight for several miles the Mataura has a broad shingle flood-bed. Below Fairlight as far as the entrance of Eyre Creek beyond Athol, but more especially between Garston and Eyre Creek, the Mataura flows over a relatively stable bed between stable banks. The greatest stability of bed occurs between Athol and Eyre Creek, where, in parts, coarse aquatic vegetation is rooted in marginal silt deposits. Eyre Creek, which is subject to severe flooding and transports much coarse gravel, renders the Mataura bed below its entrance less stable than above. In much of the bed between Fairlight and Eyre Creek, stones comprising the surface are embedded in sand and coarse grit. Below Eyre Creek the bed is generally more suitable, and heavy spawning takes place shortly above Nokomai River. Appendix F gives further particulars regarding the Mataura. Material collected is shown in detail there in Table VII.

The Series A group in Table VII comprises samples from the principal stream. Series B comprises material from the schist-bedded Whakaea sub-system tributaries, the Dome, Gows, and Argyle Burns. The lower eastern quartz gravel tributaries—Waikaka, Mairarau, and Mimihau—are

represented by Series C. Of these three, the Mimihau is of major importance. It offers, in its lower reaches, extensive areas of stable bed of gravel of suitable size with a patchy growth of vegetation. Banks are relatively stable and are willow-clad or grassed. Series D consists of samples from shingle pockets of limited extent in the rock bed of the Otamita. The sparse spawning-areas of the Tomogalak are represented by Series E.

Massing of redds did not occur in the Tomogalak, occurred to a limited extent in the principal stream and Whakaea tributaries, and much more generally in other tributary waters.

Discussion.

The five samples in Series A with losses in excess of 10 per cent. came from dirty redds, one in the vicinity of Garston and four near Athol in the reach where weed banks occur. The losses were normally low in other redds in the cleaner bed near the entrance of the Nokomai River.

Redds in the schist-bedded tributaries of the Whakaea all show low losses. Two from Argyle Burn showed losses of less than 3 per cent. This is interesting, because that stream carries sluicing debris. There redds had been made during a fresh which permitted access to a small off-shooting stream in which the flow was much reduced in times of normal volume. Mining debris in the form of fine clay particles had settled on the bed to a depth of 2 in. and gravel could no longer be seen where both redds were found. The deposit had not consolidated, nor had it penetrated any distance into the two redds. This stream has a steep gradient and is subject to fairly frequent freshes which normally could be expected to remove debris before it lies long enough to penetrate to developing ova. The position in the Waikaka (from which material is included in Series C) is very different. In it, turbidity resulting from mining operations made impossible the examination of the lowest eight miles of stream. Inspections at intervals above the turbid reach showed, over a distance of several miles, extensive areas of a medium which, except for one thing, appeared to be ideally suitable. Although gradient and size of gravel were usually excellent, surface stones were everywhere embedded in clay. The bed, which supports a rich diatom growth, has a poor fauna because shelter on the undersides of stones is lacking. This stream was followed until an abandoned gold claim, from which clay had been washed into the stream, was encountered. Immediately above it, surface stones were not embedded and redds and a good fauna were found. This stream is not given to heavy flooding, and, in any case, its very low grassed banks would enable excess waters to spread. It is difficult to believe that the ruined portions of this stream-bed can, without man's intervention, resume their former character.

Series C shows losses in excess of 10 per cent. in three samples from the Mimihau and two from the Mairarua. The two latter were contiguous and came from a very dirty medium where plants grew in dirty gravel. Two of the Mimihau samples came from dirty redds, superimposition having aggravated unsatisfactory conditions in one case. No abnormality was noted in the redd from which Sample 37, with its 15·7 per cent. loss, was obtained.

The Otamita group, Series D, comprises only pre-eyed samples. The only heavy loss shown appeared to be attributable to disturbance of some older eggs during the superimposition of others. In September, 1937, the flow over two redds, in a dirty medium in marginal waters, was so

reduced that collection of contents by ordinary methods could not be made. Disturbance of these redds showed a high proportion of dead eggs to be present.

The Series E samples represent an admirable medium of too limited an extent to be of much value.

Summary of Mataura System Data.

Of 4,443 specimens in 18 pre-eyed samples, dead pre-eyed ova = 193, or 4·34 per cent.

Of 20,122 specimens in 27 pre-eyed samples, dead pre-eyed ova = 788, or 3·92 per cent.; and dead eyed ova = 57, or 0·28 per cent.

Of 18,028 specimens in 23 pre-eyed samples, dead pre-eyed ova = 1,074, or 5·96 per cent.; dead eyed ova = 263, or 1·46 per cent.; and dead alevins = 78, or 0·43 per cent.

The 38,150 specimens in samples which had completed pre-eyed development show a loss of 1,862, or 4·88 per cent., in the pre-eyed stage. The alevin samples show a pre-eyed loss of 5·96 per cent. and an eyed loss of 1·46 per cent. Based on this ratio, with a pre-eyed loss of 4·88 per cent., the eyed-stage loss is estimated to be 1·20 per cent. Thus estimated, the total loss to hatching is 6·08 per cent. The percentage of dead alevins in alevin samples, although abnormally high at 0·43 per cent., is still extremely low.

SUMMARY OF DATA FROM SOUTHLAND AND OTAGO DISTRICTS.

Data have been presented concerning natural reproduction in six water-systems, of which four—the Waiau, Aparima, Oreti, and Waituna—lie wholly in Southland. The Mataura forms the boundary of Southland and Otago, while the Kakanui is in the northern portion of Otago. In Table VIII results from these water systems are summarized:—

Table VIII.

River-system.	Total Samples.	Total Specimens.	Estimated Loss before Hatching.			Percentage of Dead Alevins in Alevin Samples.
			As Pre-eyed Ova.	As Eyed Ova.	Total.	
			Per Cent.	Per Cent.	Per Cent.	
Kakanui ..	62	45,248	2·88	0·32	3·20	0·17
Oreti ..	112	73,804	3·32	1·32	4·64	0·10
Mataura ..	68	42,593	4·88	1·20	6·08	0·43
Aparima ..	43	35,363	6·27	0·58	6·85	0·19
Waiau ..	91	114,214	9·07	2·31	11·38	0·18
Waituna ..	28	15,443	21·62	7·67	29·29	0·06

Material from the two districts is grouped below. It is reiterated that material was not obtained from several important water-systems in the Otago district and that, from such systems as material was obtained, the different collections represent different proportions of the totals available

for collection in different waters. Subject to this, the material for Southland and Otago may be summarized as follows :—

Of 41,529 specimens in 81 pre-eyed samples, dead pre-eyed ova = 1,560, or 3·75 per cent.

Of 152,182 specimens in 175 pre-eyed samples, dead pre-eyed ova = 11,806, or 7·78 per cent. ; and dead eyed ova = 2,526, or 1·66 per cent.

Of 132,952 specimens in 148 pre-eyed samples, dead pre-eyed ova = 7,327, or 5·51 per cent. ; dead eyed ova = 1,784, or 1·34 per cent. ; and dead alevins = 260, or 0·20 per cent.

Of the 285,136 specimens from eyed-ova and alevin samples, 19,133, or 6·71 per cent., died as pre-eyed ova. The alevin samples show, with a pre-eyed loss of 5·51 per cent., an eyed loss of 1·34 per cent. On the basis of the ratio so shown there would, with a pre-eyed loss of 6·71 per cent., be an eyed loss of 1·63 per cent. Thus the estimated loss until hatching would be 6·71 per cent. and 1·63 per cent. = 8·34 per cent. The figure of 0·20 per cent. dead alevins obtained from 148 samples of alevins at different stages of development indicates a very low subsequent loss in the redds.

THE AUCKLAND DISTRICT.

There are certain important differences between the six South Island water-systems just discussed and those of the Auckland Province of the North Island. Very many rivers of the South Island and many in the southern portion of the North Island (1) flow over beds of greywacke gravels ; (2) have shingle beds extending to the sea or into short tidal reaches ; (3) have introduced salmonid stocks consisting almost exclusively of brown trout, which provide angling down into tidal waters ; and (4) rarely carry stocks of rainbow trout except in lakes and their tributary and outlet streams.

In the Auckland district (1) the gravels in stream-beds are commonly of rhyolite and pumice or of soft sedimentary rock ; (2) except in the case of small streams draining coastal ranges, the coarser gravel reaches give way to sand and finer materials at considerable distances from the sea, and trout are not sought as far down as tidal waters ; (3) rainbow trout occur in all angling waters, being the only introduced fish in some, and occurring in association with brown trout in others.

Gravel of suitable size and cleanliness for the spawning of trout occurs generally in the beds of coastal hill streams, but in the major water-systems draining the central portion of the province it is largely limited to the upper waters and to the hill tributaries. The troutless Piako has little, if any, suitable gravel. Most of the lower seventy or eighty miles of the Waikato bed comprises materials too fine for utilization by trout. The Waikato tributaries in this length, apart from those comprising the important Waipa sub-systems, are few and small. The Waipa, although better provided with nursery areas, has itself an unsuitable bed at least as far up as Otorohanga, some fifty-nine miles from where it joins the Waikato a further sixty-one miles from the sea. Otorohanga, one hundred and twenty miles by river from the sea, is only 122 ft. above sea-level. (In Southland, on the Mataura, the height of Garston, one hundred and thirty-two miles from the mouth, is 1,009 ft. ; on the Oreti, the height of Mossburn, eighty-four miles

inland by river, is 761 ft.). Although gravel of pea size and greater occurs from forty to ninety miles up the Waihou, the bed is generally unsuitable for spawning until Okoroire is passed, some ninety miles up. Greywacke gravels and others, similarly hard and heavy, which are almost invariably dominant in the stream-beds of the south, are found only in limited areas of the Auckland Province. Extensive plains of very coarse alluvial gravels are lacking. The light acidic rocks—rhyolite and pumice—almost alone provide such gravels as are found in the Waikato River and in much of the Waihou system. Hard and heavy gravels, formed from the heavier igneous rocks, are encountered in the short and steep Whanga and Colville Range tributaries of the Waihou. The streams of the Waipa sub-system and two lower Pararoa Range Waikato tributaries have reaches of hard heavy gravels. The Awakino, although occasionally flowing over bed-rock, has generally a bed of gravel formed largely from soft Miocene rocks. Soft Pliocene and Miocene rock is encountered in the beds of many streams on either coast in the central portion of the North Island. Locally the term "papa" is applied to such rock. Gravels of harder sedimentary rock comprise the bed of the Wanganui River at Taumarunui.

The collection of material was limited to streams comprising the Waihou, Waikato, Awakino, and Wanganui systems. On the Waikato, observations were limited to the principal stream and certain tributaries below its junction with the Mangakino, one hundred and fifty miles from the mouth. The Wanganui was examined only in the vicinity of Taumarunui. Streams examined are shown in Fig. III, in which the approximate localities of places sampled or inspected are indicated.

THE WAIHOU (OR THAMES) SYSTEM.

The upper portion of the Waihou system—from Okoroire up—comprises some twelve miles of the Waihou, eight miles of the Waimakariri, and a small tributary, the Little Puriri. These streams (1) are spring-fed, (2) have small watersheds of very permeable materials, (3) have very stable beds of rhyolite and pumice gravel and sand, (4) are affected to a minimum extent by freshes, and (5) carry extraordinarily heavy stocks of small rainbow trout. Eels, which are common in New Zealand streams and reach very large sizes, are not known in the system above the Okoroire Falls. The falls, while are of no great height, present a fast unbroken flow of water up which, it is stated locally, trout can pass while eels cannot. Damp rock walls or moss-grown slopes, which permit eels to climb many falls, are lacking here.

In the ninety miles of the principal stream below the falls generally the stream is confined to stable and steeply rising vegetation-clad banks. This length of river is reputed to carry a meagre stock of trout of larger average size than above the falls. In the forty-five miles of water between Te Aroha and the mouth the fall is less than 1 ft. per mile. In the forty-five miles of water between Okoroire and Te Aroha visibility is limited by the opalescence of the water. In this length, examination of material dredged from the river, of material in cuttings in the banks, and of such shallow portions of the bed as could be inspected suggested that most of the bed consisted of material finer than pea gravel. Generally the stream is over $2\frac{1}{2}$ ft. in depth and flows steadily without many runs and pools. In a rippled shallow of suitable gradient near Okauia Springs the bed comprised gravel to $2\frac{1}{2}$ in.

Much of the surface gravel there was partially embedded in finer material and no redds were found. Observations were somewhat inconclusive, but they indicated the improbability of extensive spawning taking place.

Only two tributaries of importance enter the Waihou from the west below Okoroire. These are the Oraka and the Mangawhero. The former, although spring-fed, is affected by freshes in its thirty-mile course. It is from 10 ft. to 20 ft. wide, is strictly confined to stable, vegetation-clad banks, and has a bed predominantly of rhyolite gravel of less than pea size. From place to place short reaches of coarser gravel occur. The Mangawhero—spring-fed, sand-bedded, and water-cress margined—has, despite spasmodic liberations, failed to develop a stock of trout. No gravel suitable for spawning was observed in this stream.

A series of short tributaries drain westwards into the Waihou from the steep and narrow Whanga and Colville Ranges. Of these, those comprising the Waiomou and Ohinemuri sub-systems, together with two small streams entering the tidal portion—the Hikutaia and Puriri—provide a limited amount of angling. In the fifty-five miles of water between the entrances of the Ohinemuri and Waiomou, numerous tributaries enter. All are of small size; all course steeply down over bed-rock and large boulders to enter, after flowing for short distances through hill-foot alluvium. A cursory inspection of a series of these streams disclosed none offering any considerable extent of gravel bed suitable for spawning.

The chief characteristics of the upper portion of the Waihou are noted in Appendix G, where details of collections made are set out in Table IX.

Discussion.

Sample 8, from the Waimakariri, shows a loss of 35·6 per cent. The redd was badly silted as a consequence of the displacement of an obstruction upstream from it. This sample afforded a remarkable instance of arrested development. Eggs, approximately uniform in diameter at 5·7 mm., contained embryos varying in length from 6·7 mm. to 13 mm. The three Waihou samples with heavy losses came from an area where the intensity of spawning had been sufficient to develop an extensive wave formation in the gravel bed. In each redd the silt content was abnormally great, apparently as a consequence of the construction of other redds immediately in front.

The spawning-areas of the upper Waihou are less extensive than the extraordinary density of stock suggests. It seems reasonable to attribute the density of stock to the absence of a usual lethal factor. Eels, which generally abound and reach large sizes in New Zealand waters, are, so far as can be ascertained, absent from the Waihou above Okoroire. Eels are known to prey on trout elsewhere. Shags of the large black (*Phalacrocorax carbo*) and smaller white-throated species (*P. brevirostris*) are found in unusual abundance on this water and are known to feed on trout there. These birds also feed on the fresh-water crayfish (*Paranephrops*), which is also extraordinarily abundant in the upper Waihou waters. In view of the widespread belief in New Zealand that the depredations of shags are of great significance, and in view of the little attention paid to the possibilities of depredations by eels, the foregoing facts are of interest.

Horse-drawn scoops are employed at one point on the upper Waihou to obtain gravel for road-construction purposes. Much of the gravel so obtained is that loosened from the fairly consolidated bed by trout in making redds.

The Waiomou Sub-system.

Examination of the Waiomou itself from the entrance of the Raparapa to a mile below that of the Omohine did not provide evidence that fish spawned there. Although the bed is of gravel of suitable size, examination showed that, where the gradient was suitable, surface stones were either embedded in sandy material or were overlying a mixture consisting predominantly of grit and sand.

The Omohine and Raparapa provide spawning-facilities for a number of large trout, most of which enter from the Waihou. In both, spawning is largely limited to the lower mile or two where the streams flow through coarse alluvium after dropping steeply downhill. A higher tributary—the Kakahu—flows through a similar formation. The Omohine, in the spawning-area, is confined to one channel by low banks of eroded alluvium and, in parts, of sloping shingle. The bed comprises a mixture of rhyolite and heavier rock ranging from boulders of 2 ft. down to shingle of 2 in. Usually it is fairly firmly cemented. Redds are made both in shingle pockets in areas of protruding boulders and in reaches of finer material. Generally the stream is from 10 ft. to 16 ft. wide and less than 18 in. deep. Low banks—1 ft. to 3 ft.—permit the spreading of flood-waters. The bed was considerably altered by an autumn flood early in 1937. The modifications were, in part, consequent on the removal from the bed, for road-construction purposes, of most of the largest boulders.

The Raparapa emerges from a gorge and flows quietly between low banks over a broad alluvial flat. It is from 10 ft. to 20 ft. wide and usually less than 2 ft. in depth. The bed comprises rhyolite gravel of to $4\frac{1}{2}$ in. at the top of the flat and to pea gravel at the bottom. It is very unusual for redds to be constructed in a bed comprising stones of 3 in. to 4 in. devoid of any considerable quantity of finer material. In this stream a number of redds were found in places where such material continued to a depth of 6 in. In such cases, excavation had continued into the more cemented bed underneath, and ova were commonly found at depths of 12 in. to 15 in. below the surface of the bed. The depth of the excavations is somewhat remarkable, but the fish (rainbow trout) were fairly large—$2\frac{3}{4}$ lb. to 6 lb.—and rhyolite is a very light stone.

Both streams are lacking in cover for large fish. Spawning fish in them are extremely vulnerable to poaching and stocks suffer severely in this way. Possibly to this fact can be attributed the relatively low degree of utilization of spawning-areas. Samples from the Waiomou sub-system comprise Series B, Table IX, in Appendix G.

Discussion.

Apart from the 11·4 per cent. loss in Sample 37R, mortality is low in all cases. In this case silt had settled in a portion of the redd during the construction of a more recent, contiguous redd. The two most advanced alevin samples—45R and 46O—were remnants of lots, some of which had emerged.

Summary of Waihou System Data.

Of 10,049 specimens in 10 pre-eyed samples, dead pre-eyed ova = 280, or 2·79 per cent.

Of 13,461 specimens in 18 eyed samples, dead pre-eyed ova = 629, or 4·67 per cent.; and dead eyed ova = 36, or 0·27 per cent.

Of 9,811 specimens in 18 alevin samples, dead pre-eyed ova = 611, or 6·23 per cent.; dead eyed ova = 20, or 0·20 per cent.; and dead alevins = 7, or 0·07 per cent.

Of 23,272 specimens in the 36 samples of eyed ova and alevins, 1,240, or 5·33 per cent., died in the pre-eyed stage. The alevin samples show an eyed loss of 0·20 per cent., with a pre-eyed loss of 6·23 per cent. On this basis, the eyed-stage loss, which would be found with a pre-eyed loss of 5·33 per cent., is estimated at 0·17 per cent. Thus the estimated total loss hatching is 5·50 per cent. The alevin-stage samples contained 9,180 larval fish, of which only 7 were dead when recovered.

THE WAIKATO SYSTEM.

Observations on the Waikato system were limited to the lower one hundred and fifty miles of the principal stream—that is, from ten to fifteen miles above Lake Arapuni down to tidal waters—and to tributaries entering this portion. Higher up, Lake Taupo supplies the bulk of the Waikato system water and contributes to the stability of the stream-bed by controlling the volume. The Waipa sub-system is the only important tributary in the lower one hundred and fifty miles. Others are very small in size and commonly have impassable falls at short distances from their mouths.

Above Arapuni Lake, the Waikato is from 30 yards to 70 yards wide and is commonly over 4 ft. deep. It follows a sometimes turbulent course through a narrow valley over a fairly stable bed comprising, in part, rhyolite and pumice bed-rock and elsewhere boulders and gravel. Opalescent water limits visibility. It contains an abundant stock of rainbow trout. To what extent trout spawn in this upper area is not known.

Lake Arapuni is artificial, is from twelve to sixteen miles long and two hundred to eight hundred yards wide, and has a perceptible flow at each of its narrow ends. The Waipapa, entering from the west at the head, flows over bed-rock and lacks gravel in at least its lower six miles. A very small tributary, entering from the west shortly below the Waipapa, provides spawning-facilities for a few dozen fish in a medium which is too fine and dirty to be satisfactory. A number of other small tributaries, which formerly flowed over gravel in their lower reaches, have been covered back to the falls over which they now enter the lake. Barnett (1938) states that formerly trout spawned in the lower portions of the Makomako and other of these tributaries; also, that the principal stream was shallow in many places where the bottom was of shingle and sand, and that, to his knowledge, trout spawned in several places. The extremely crowded state of the redds, in an unsatisfactory medium in the small tributary below the Waipapa, indicates a present insufficiency of spawning-ground. The construction of the dam, while greatly increasing the extent of water to be stocked, made available no new spawning-areas and ruined nearly all those previously there. A second effect of the construction of the dam was that eels gained access to the upper waters. Previously, these predaceous fish extended upwards from the sea, through the former Hell's Gate Rapid at the dam-site, until, a short distance above, their upward passage was blocked at a point where unbroken water flowed swiftly between smooth rock walls. A picturesque Maori legend attributes their failure to pass this point to the insatiable appetite of a taniwha—a legendary monster—which is supposed to have lived there. It would seem that here, as in the Waihou at Okoroire, swiftly flowing water which could not be avoided by recourse

to eddies or to wet rock walls proved an effective barrier to eels. (The writer did not see the Waikato before the construction of the dam, and in arriving at this interpretation has relied on facts furnished by Barnett (*loc. cit.*), who was intimately acquainted with the river.)

For some eight miles below Arapuni Dam, down to below the entrance of the Pokaiwhenua at Horahora, the Waikato is generally a swiftly flowing and, less commonly, a turbulent stream. Much of it is over 6 ft. in depth, and even under optimum conditions opalescence precludes the inspection of the bed except in shallow portions. The bed consists rarely of bed-rock, sometimes of huge rhyolite blocks, and more commonly of rhyolite and pumice sand and gravel. It is usually richly clad with diatom and algal growths. Because (1) this reach carries a very abundant stock of large rainbow trout, (2) in 1936 naturally produced fry were observed in it at a number of places before hatchery fry were liberated, (3) spawning-facilities in accessible tributaries are extremely limited and excessively used, and (4) because the type of bed used in these tributaries occurs in quantity in the principal stream, it seems reasonable to believe (*a*) that considerable spawning takes place in the main stream, (*b*) that results of examinations of redds in tributaries with beds of like character should give some indication of the conditions in portions of the principal stream. No redds were examined in the main river. Examination was made of all tributaries entering this reach. Of them the two largest—the Little Waipa and Pokaiwhenua—have, in the short lengths between inaccessible falls and their mouths, beds of sand with some large boulders and bed-rock. These areas have no significance as nursery areas for the Waikato. A number of trial redds, from one of which a sample was obtained, were found in a very small lower Pokaiwhenua tributary. Generally, in it redds were not completed because of the unsatisfactory medium—much sand with some pea gravel. The same remark applies to the Waitete, although, in its greater length, more suitable material and more redds are found. This small creek, which enters immediately below the Arapuni Dam, offers a greater extent of accessible water than the other tributaries do. The extent of suitable bed is very limited. In a Waikato backwater across from the mouth of the Waitete the level rises and falls as waves enter and recede. The entrance to the backwater is very narrow. Attempts—largely abortive—at redd-construction are made in the sandy bed at the entrance. One redd was found in a small seepage course at the top of the backwater. Spawning occurs in more satisfactory material in two very small tributaries, Hui Creek and a creek immediately opposite the Little Waipa mouth. In each case falls limit access to the lower 200 yards of water and suitable deposits are of very small extent. In these two streams fish spawn in the coarsest material offering—material to 2 in.—which is coarser than that found in the other tributaries. Samples from these waters comprise Series A of Table X in Appendix H.

The gradient of the Waikato decreases from Horahora downwards. At Cambridge, fourteen miles lower down, and ninety miles by river from the sea, the stream is less than 150 ft. above sea-level. At Hamilton, seventy-four miles from the sea, it is less than 100 ft. above. Sand forms most of the visible bed from Horahora down.

The Little Waipa above the fall is similar in size and nature of bed to the Pokaiwhenua, which enters shortly below it, and to the Oraka, in the Waihou system. Observations were limited to the lower two miles above

the fall and embraced a small tributary, the Otarnoroa. Much of the Little Waipa bed is of stable sand and finer materials which, apart from detritus, are of rhyolite and pumice origin. Gravel to 2½ in., which occurs from time to time, is commonly too dirty to provide a first-class medium. Such as is available is used excessively, for redds are generally overlapping. The Otarnoroa bed is commonly of pea gravel and finer matter. Many trial redds, which have been abandoned without any substantial deposition of ova, occur; completed redds are rare. Samples from the Little Waipa and its tributary comprise Series B of Table X.

Discussion.

The five samples from opposite the Little Waipa comprise two groups of contiguous redds made in a slightly dirty medium. Samples 1C and 3C were at the upstream ends of the two groups and show lighter losses than those below them. The fact that Sample 8C survived successfully to the eyed stage suggests that the medium was not unsuitable until modified by the addition of fine matter during the later construction of redds in front.

Sample 4P came from a dirty medium where the largest particles were of pea size. The sample itself is of small size—a usual occurrence where trial redds are plentiful. (See also Samples 9B, 7W, and 20O.)

Sample 6H came from the only patch of suitably sized rhyolite gravel in Hui Creek.

Sample 9B is of interest in that it came from a small patch of angular pieces of pumice over which a trickle of water was flowing. Besides this sample from the head of the backwater, the sand bed at its mouth yielded several. These comprised three groups: seventy-nine specimens, including ten dead, from an area of 3½ ft. by 2½ ft.; fifty-one specimens, including forty-six dead, from an area 3 ft. by 2 ft.; and fifty four specimens, including thirty-two dead, from an area of 4 ft. by 2 ft. So far as could be determined, by differences in size and colour of specimens, the first group was part of the product of five females, the second of two, and the third of four. A local observer stated that eels were seen apparently feeding on ova as trout spawned at this spot. This alone would not account for the small numbers of eggs found. It is not unusual for a few eggs only to be shed by fish in trial redds such as these.

Sample 10A came from a somewhat dirty redd in front of which a second redd had been constructed.

The Series A samples, while of interest in affording evidence of reactions to different conditions in relatively unimportant spawning-areas, are not necessarily indicative of conditions everywhere in the main river, where the bulk of the fish spawn. The extremes of conditions offering in the Waikato, however, are not likely to exceed those in the areas represented by Series A and B of the Waikato system samples and Series A from the Waihou system: all three series represent areas of stream-bed in the same rhyolite and pumice country which the Waikato traverses.

The redds in the Little Waipa were made in a rather dirty medium over which the current was less than usual. As in Waituna Creek, which is even slacker and more weed-grown, frequently redds were short and high. These rose very sharply from the bed and presented amphitheatre-shaped faces to

the current. The material used was a "border line" one, in which slight modifications could cause heavy losses. The alevin samples collected were about the earliest of the season and consequently had had a greater chance than the average of being adversely affected by superimposition. These redds afford some good instances of superimposition effects. Samples 11 and 13 formed a tandem contiguous group, while 12 and 18 were parallel and contiguous. In the former case, a heavy loss resulted in the older sample from the construction of the redd immediately in front. Samples 15, 22, and 25 comprised another contiguous group, arranged tandem fashion, with the more recent of any two samples in front of the older. Samples 21 and 24 were from separate redds in slacker water. Their contents had suffered from the settling of fine detritus at their forward ends.

Summary of Waikato System (Rhyolite-pumice Bed) Data.

Of 5,710 specimens comprising 8 pre-eyed samples, dead pre-eyed ova = 520, or 9·11 per cent.

Of 7,962 specimens comprising 7 eyed samples, dead pre-eyed ova = 974, or 12·23 per cent.; and dead eyed ova = 30, or 0·38 per cent.

Of 4,716 specimens comprising 10 alevin samples, dead pre-eyed ova = 1,237, or 26·23 per cent.; dead eyed ova = 792, or 16·79 per cent.; and dead alevins = 113, or 2·39 per cent.

The material is unsatisfactory, both because it does not include any from the main spawning-areas in the principal stream and also because, to a greater extent than elsewhere, alevin samples are those which resulted from the earliest eggs spawned and thus had most chance of being adversely affected by superimposition.

The Waipa Sub-system.

Collections were made in three major spawning-areas—those of (1) the Waipa itself and a small tributary, the Tauraroa: (2) the Mangaokewa: and (3) the Mangatutu, a Puniu branch. The sixty-one miles of the Waikato below the Waipa junction, the fifty-nine miles of the Waipa below Otorohanga, the lower fourteen miles of the Puniu, and the lower sixteen miles of the Mangaokewa between Te Kuiti and Otorohanga are unsuitable for the spawning of trout. They comprise waters which flow quietly between stable and often willow-clad banks over beds of fine materials, which support some growth of coarser aquatic plants.

In the Waipa an inspection was made of much of the gravel bed in sixteen miles of water between Otorohanga and Toa's Bridge and for six miles into the hills beyond. Samples were taken exclusively from five miles of water below Toa's Bridge, little evidence of spawning being found in other areas. By far the greatest part of the bed comprises gravel which is either too coarse or of which the surface stones are too embedded. The Waimahora—a small tributary—adds its own and the Tauroroa waters to the Waipa at the bridge. The upper waters of the Tauroroa provided several samples. The chief features of the principal stream of this sub-system are recorded in Appendix H, where details of collections made are shown in Table XI.

Mangatutu and Mangaokewa Streams.

The Mangatutu, which has a gravel bed, is much better provided with spawning-areas than the Puniu, which it enters. The bed of the latter is often of bed-rock, and gravel occurs irregularly until approaching and below the junction of the Mangatutu. The Mangatutu is from 8 ft. to 18 ft. in width, commonly less than 15 in. in depth, and is usually confined by low stable banks. The bed is a stable one of hard gravel. Over a distance of at least twelve miles, where the stream ripples along a grassy valley floor, the bed offers spawning-ground for many fish. Samples were taken over an eight-mile length of water. The stock consists of brown and rainbow trout.

The Mangaokewa, above Te Kuiti where it leaves the hills, is from 18 ft. to 25 ft. in width and most commonly from 12 in. to 18 in. in depth. Like the former stream, it has a fairly stable bed and shows little evidence of severe flooding. Most of the samples were obtained from redds where there were low grassed banks—that is to say, from places where flood-waters could easily spread without scouring the bed. In more confined portions of the hill section surface stones of the bed were usually embedded and diatom-clad. Samples were obtained from three localities in the six miles of water above Te Kuiti. The stock comprises brown and rainbow trout.

Discussion.

Only five of the forty-five samples show heavy losses. In three cases the losses are attributable to bad choice of spawning-sites. Sample 28 came from a quite abnormal redd—one made where the bed fell away sharply in a downstream direction, with the result that the mound of the redd was below the level of the bed immediately in front. Silt had settled heavily in this redd. The redds which yielded Samples 52 and 62 had both been constructed in marginal waters during freshes and silt had settled as the waters subsided. It seemed likely that Sample 62 had, for a while, been left in stagnant water. Samples 29 and 47 came from redds in which debris had settled during the construction of redds immediately in front.

Generally the redds in these four streams are dirtier than in many others. The safety margin is not great, but is sufficient where usual freshes do not cause marked turbidity.

Summary of Waipa Sub-system Data.

Of 11, 957 specimens in 17 pre-eyed samples, dead pre-eyed ova = 1,389, or 11·62 per cent.

Of 21,806 specimens in 21 eyed samples, dead pre-eyed ova = 540, or 2·48 per cent.; dead eyed ova = 8, or 0·04 per cent.

Of 3,001 specimens in 7 alevin samples, dead pre-eyed ova = 322, or 10·73 per cent.; dead eyed ova = 83, or 2·77 per cent.; and dead alevins = 3, or 0·10 per cent.

It will be noticed that the chance occurrence of heavy losses in the pre-eyed and alevin samples only, accounts for the variation in pre-eyed losses shown by the three groups. Of the 24,807 specimens in the eyed and alevin samples, dead pre-eyed ova number 862, or 3·47 per cent. On the usual basis of estimation the eyed losses would be 0·90 per cent., bringing the total loss before hatching to 4·37 per cent.

Summary of the Waikato System Data.

This summary is given subject to the comment that the pre-eyed and eyed samples came predominantly from the Waipa sub-system waters, which are thought to have more limited spawning-areas than the Waikato itself has.

Of 17,667 specimens in 25 pre-eyed samples, dead pre-eyed ova = 1,909, or 10·80 per cent.

Of 29,768 specimens in 28 eyed samples, dead pre-eyed ova = 1,514, or 5·09 per cent.; and dead eyed ova = 38, or 0·13 per cent.

Of 7,717 specimens in 17 alevin samples, dead pre-eyed ova = 1,559, or 20·20 per cent.; dead eyed ova = 875, or 11·34 per cent.; and dead alevins = 116, or 1·50 per cent.

Of the 37,485 specimens in samples which had completed pre-eyed development, 3,073, or 8·20 per cent., died before the eyed stage. The eyed loss, estimated as before, is 4·60 per cent. It will be noted, however, that much of the alevin material, which forms the basis of this estimation, came from the Little Waipa, where there is reason to believe that the alevin samples taken showed losses above the average for that stream. The value of the figure 12·80 per cent. thus obtained for losses before hatching in the Waikato system is very doubtful. The alevin loss of 1·50 per cent. is higher than usual: most of these dead alevins came from one Little Waipa redd.

THE AWAKINO SYSTEM.

The Awakino drains steep wooded coastal ranges and enters the Tasman Sea eighty-eight miles south of the Waikato mouth. It is distinguishable from all other streams sampled in that much of the gravel in its bed is of soft sedimentary rock. Stones powder when rubbed lightly together. This stream is more fully described in Appendix I, where samples collected from it are shown in Table XII.

Discussion and Summary of Awakino Data.

A heavy loss is shown by only one of the samples—No. 8, which came from a dirty redd. These samples are of especial interest in that they show that there is not necessarily any correlation between the nature of the gravel and the amount of accompanying fine material. Granite and rhyolite, which break into coarse particles, may, in a stream-bed, offer a dirtier medium than mudstone gravel, which gives fine particles, for the finer material which accompanies any gravel is not necessarily the product of the disintegration of that gravel.

Results are summarized as follows :—

Of 1,491 specimens in 2 pre-eyed samples, dead pre-eyed ova = 25, or 1·68 per cent.

Of 2,108 specimens in 3 eyed samples, dead pre-eyed ova = 68, or 3·23 per cent. ; and dead eyed ova = 0, or 0·00 per cent.

Of 4,104 specimens in 4 alevin samples, dead pre-eyed ova = 303, or 7·38 per cent. ; dead eyed ova = 172, or 4·19 per cent. ; and dead alevins = 2, or 0·05 per cent.

The 6,212 specimens from the 7 samples which had completed pre-eyed development show a loss of 371, or 5·97 per cent., as pre-eyed ova. Estimated on the basis of eyed to pre-eyed losses in alevin samples, the eyed-stage loss would be 3·39 per cent. This would give a figure of 9·36 per cent. for losses before hatching. Subsequent losses are low.

THE WANGANUI SYSTEM.

The Wanganui system is one of the major ones draining into the Tasman Sea on the western coast of the North Island. The collections from it are small, and were made in only four miles of the principal stream, out of a total of two hundred miles, and in a few of a number of important tributaries. The examination of the principal stream was restricted to the vicinities of Taumarunui and Manunui and the mouth of the Whakapapa, and, of tributaries, to portions of some entering near Taumarunui. In this area waters carry good stocks of brown and rainbow trout. The principal stream is confined to one channel of from forty yards to seventy yards wide in a narrow alluvial flat between low deforested hills. Banks are commonly stable and low. Flood-waters may spread without scouring greatly. The bed comprises materials varying from large boulders in more rapid portions to sand in slacker portions of pools. Much of the bed is of hard gravel of 2 in. to 10 in.

Data relating to samples from the Wanganui River are given in Table XIII, Appendix J. Included are three samples from tributary waters—one each from the Pungapunga, Ongarue, and Waimiha. The place of origin of each is indicated by the use of the initial letter of the stream.

Discussion and Summary of Wanganui System Data.

The heavy loss shown in one case resulted from the diversion of current and precipitation of silt consequent on the construction of a contiguous redd on the upstream side :—

Of 667 specimens in 2 pre-eyed samples, dead pre-eyed ova = 10, or 1·50 per cent.

Of 6,006 specimens in 11 eyed samples, dead pre-eyed ova = 327, or 5·44 per cent. ; and dead eyed ova = 0, or 0·00 per cent.

SUMMARY OF DATA FROM AUCKLAND DISTRICT.

The material from the Auckland District comes from twenty-two streams comprising four water-systems It consists of 102,849 specimens from 138 redds :—

Of 29,874 specimens in 39 pre-eyed samples, dead pre-eyed ova = 2,224, or 7·44 per cent.

Of 51,343 specimens in 60 eyed samples, dead pre-eyed ova = 2,538, or 4·99 per cent.; dead eyed ova = 74, or 0·14 per cent.

Of 21,632 specimens in 39 alevin samples, dead pre-eyed ova = 2,473, or 11·43 per cent.; dead eyed ova = 1,064, or 4·93 per cent.; and dead alevins = 125, or 0·58 per cent.

Of the 72,975 specimens which had completed pre-eyed development, 5,011, or 6·87 per cent., had died before eyeing. Based on the proportions of eyed to pre-eyed dead in alevin samples, the eyed loss to accompany a pre-eyed loss of 6·87 per cent. is estimated at 3·04 per cent.—thus a total loss of 9·91 per cent. before hatching is shown. The small proportion of dead alevins indicates a low subsequent loss before the fry emerge.

SUMMARY AND DISCUSSION OF NEW ZEALAND DATA.

A. QUANTITATIVE STUDIES.

With material for qualitative studies, data were sometimes obtained which give some indications of the extent of the total depositions of ova. Those obtained by the counting and sampling of redds are based on too few samples to give really significant results. They are included, however, (*a*) because they serve to illustrate a useful field method of assessing spawning-areas in smaller streams, and (*b*) because the estimates made are at least approximate enough to show that samples taken for qualitative purposes comprise very small portions of material available, even in streams more heavily sampled than many were. Other data, obtained from the trapping of runs of spawning trout in more important streams, again give some indication of the quantities of eggs produced in them alongside those taken for qualitative purposes. Data obtained in these ways are given with comments in Appendix K.

B. QUALITATIVE DATA.

Altogether the collections include 542 samples comprising 429,514 specimens. The material comes from sixty-four streams which form parts of ten water-systems. Losses estimated from material from different systems are shown in Table XIV :—

Table XIV.

Water-system.	Percentage Losses.			Percentage recovered as Dead Alevins.
	As Pre-eyed Ova.	As Eyed Ova.	Total to Hatching.	
Kakanui	2·88	0·32	3·20	0·17
Oreti	3·32	1·32	4·64	0·10
Mataura	4·88	1·20	6·08	0·43
Waihou	5·33	0·17	5·50	0·07
Wanganui	5·44	No data	No data	No data
Awakino	5·97	3·39	9·36	0·05
Aparima	6·27	0·58	6·85	0·19
Waikato	8·20	4·60	12·80	1·50
Waiau	9·07	2·31	11·38	0·18
Waituna	21·62	7·67	29·29	0·06

It will be noted that in all cases pre-eyed losses exceed eyed losses. No constant ratio is maintained between the two loss groups. However, some tendency is exhibited for eyed losses to increase as pre-eyed losses increase. The generality of the rule that ova are especially vulnerable during pre-eyed development is exemplified by a study of data relating to individual redds. The alevin samples, which had completed both eyed and pre-eyed development, numbered 187. In 173 of these samples pre-eyed losses exceeded eyed losses; in 3 cases they equalled them; in only 11 cases did they exceed them. Normally redds become progressively dirtier, and therefore less suitable, as incubation proceeds. At the same time, this is countered by a reduction in vulnerability of ova. Changes of a more extreme nature than usual in immediate surroundings during eyed development would account for these 11 cases.

Dead alevins recovered do not represent the total larval losses which could have occurred. Most samples had yet to complete larval development when taken. In the more advanced samples earlier dead could have decomposed. The reduction, by decomposition, of alevins to an irrecoverable stage is a much more rapid process than that of eggs (Hobbs, 1937). Both because samples from some water-systems are insufficient, and because different periods of alevin development are represented by different sets of material, data relating to losses as alevins have little comparative value.

No correlation is shown between the nature of the rock of which coarse gravels consist and the extent of losses. The Kakanui, Oreti, and Waiau samples came mainly from areas of greywacke gravel. Waituna Creek, with its hard quartz gravels, shows heavier losses than the Awakino, where much of the gravel is of soft sedimentary rocks. The differences in the extent of losses result largely from differences in the proportion and nature of the material finer than gravel present. The greater concentration of redds in some streams than others affects the extent of the superimposition loss. In so far as such losses result from the displacement on to lower redds of fine material, these losses are conditioned by the nature of the bed.

In the case of the Waiau system, doubt has been expressed as to whether or not some eggs were inherently less resistant to adverse environmental effects. Elsewhere observations suggested that the nature of streambeds rather than the quality of ova determined the extent of the loss. This was so whether the eggs were those of brown or of rainbow trout. Of the stocks of different water-systems, those of the Waihou and Awakino comprise rainbow trout; those of the Waikato and Wanganui, brown and rainbow trout; that of the Waiau, mainly brown trout with a few rainbow trout and Atlantic salmon. The stocks of other streams are brown trout ones. While observations did not show that the ova of both species of trout react equally to the same adverse conditions, it is felt that, had any considerable difference existed, it would have been noticed.

In Table XV are shown the loss frequencies for different water-systems; also, the percentage of total samples from each system showing losses in excess of 10 per cent. is given.

TABLE XV.

River-system.	Loss Frequencies: Numbers of Samples grouped under Percentage Losses.											Total Samples	Percentage showing less than 10-percent. Loss.
	0–4·9.	5–9·9.	10–19·9.	20–29·9.	30–39·9.	40–49·9.	50–59·9.	60–69·9.	70–79·9.	80–89·9.	90–100.		
Pre-eyed Samples.													
Kakanui	15	..	1	..	..	..	..	..	..	..	..	16	93·8
Oreti	18	2	..	..	..	..	..	..	..	..	..	20	100·0
Mataura	13	3	1	1	..	..	..	..	..	..	..	18	88·9
Waihou	9	1	..	..	..	..	..	..	..	..	..	10	100·0
Wanganui	2	..	..	..	..	..	..	..	..	..	..	2	100·0
Awakino	2	..	..	..	..	..	..	..	..	..	..	2	100·0
Aparima	6	..	..	..	..	..	..	..	..	..	..	6	100·0
Waikato	17	2	2	1	..	1	1	..	..	..	1	25	76·0
Waiau	12	4	1	1	..	..	..	..	..	..	..	18	88·9
Waituna	2	1	..	..	..	..	..	..	..	..	..	3	100·0
Percentage distribution of total pre-eyed samples	80·1	10·8	4·2	2·5	..	0·8	0·8	..	..	..	0·8	120	90·9
Eyed Samples.													
Kakanui	23	2	3	..	..	..	..	..	..	..	..	28	89·3
Oreti	33	14	2	1	..	..	..	..	..	..	..	50	94·0
Mataura	21	5	..	..	..	1	..	..	..	..	..	27	96·3
Waihou	10	7	..	..	1	..	..	..	..	..	..	18	94·4
Wanganui	8	2	..	..	..	1	..	..	..	..	..	11	90·9
Awakino	3	..	..	..	..	..	..	..	..	..	..	3	100·0
Aparima	8	2	1	..	1	..	..	1	..	..	..	13	76·9
Waikato	21	4	1	1	..	..	..	..	..	..	1	28	89·3
Waiau	21	7	6	1	1	..	2	..	..	..	..	38	73·7
Waituna	4	3	2	1	6	2	..	1	..	..	..	19	36·8
Percentage distribution of total eyed samples	64·6	19·6	6·4	1·7	3·8	1·7	0·9	0·9	..	..	0·4	235	84·2

Alevin Samples.

Kakanui	15	2	..	1	..	..	..	..	..	..	..	18	94·4
Oreti	30	3	6	1	1	..	..	1	..	..	..	42	78·6
Mataura	14	1	4	2	..	..	..	2	..	..	..	23	65·2
Waihou	8	6	3	1	..	..	..	..	..	..	..	18	77·7
Wanganui	*	*	*	*	*	*	*	*	*	*	*	*	*
Awakino	2	1	..	..	1	..	..	..	..	..	..	4	75·0
Aparima	19	..	2	1	1	1	..	..	..	..	..	24	79·2
Waikato	4	3	2	1	3	..	..	1	2	1	..	17	41·2
Waiau	12	8	6	4	2	2	1	..	..	..	..	35	57·1
Waituna	..	..	6	..	..	..	..	..	..	..	..	6	0·0
Percentage distribution of total alevin samples	55·8	12·8	15·5	5·9	4·3	1·6	0·5	2·1	1·0	0·5	0·0	187	68·6

* No data.

Of 71,403 specimens in pre-eyed samples, total dead numbered 3,784, or 5·29 per cent.

Of 203,525 specimens in eyed samples, total dead numbered 17,044, or 8·37 per cent.

Of 154,586 specimens in alevin samples, total dead numbered 13,036, or 8·43 per cent.

As is to be expected, specimens which had yet to complete the vulnerable stage of development show a lower percentage loss. This also is the reason for the increase, from the pre-eyed to the eyed group, in the number of samples showing losses of over 10 per cent. The percentage of total specimens recovered dead is much the same in the eyed-ova and alevin samples, yet the heavier loss groups are much more strongly represented in the alevin samples. The apparent conflict is explained when the size of the samples is taken into consideration. The average number of specimens in all eyed samples is 866 : in the eyed samples, with losses of 10 per cent. or more, it is 1,135. The latter samples are of greater average size because twenty-five of the thirty-seven came from the Waikato, Waiau, and Waituna systems, in which the eyed samples averaged 1,168 specimens each. The alevin samples from all systems average 827 each ; those with losses in excess of 10 per cent. average only 680 specimens. Of the alevin samples with losses of 10 per cent. and more, 73 per cent. came from systems in which the average size of such samples was below the average size of all of the alevin samples. The approximately equal percentage loss shown by the total eyed and total alevin samples results from the facts that the fewer eyed samples with heavy losses are above average size while the more numerous alevin samples with heavy losses are below average size.

In Table XVI is shown, in respect to eyed, alevin, and combined eyed and alevin samples, (1) the percentage of samples falling into each of the successive loss groups, and (2) the percentage of total dead contributed by samples in each group :—

TABLE XVI

Percentage Loss Group.	0–9·9.	10–19·9.	20–29·9.	30–39·9.	40–49·9.	50–59·9.	60–69·9.	70–79·9.	80–89·9.	90–100.	Totals.
Eyed samples	84·2	6·4	1·7	3·8	1·7	0·9	0·9	..	..	0·4	235 samples.
Percentage dead in each loss group	31·7	15·2	7·0	21·0	11·2	7·2	5·6	..	..	1·1	17,044 dead specimens.
Alevin samples	68·6	15·5	5·9	4·3	1·6	0·5	2 1	1·0	0·5	..	187 samples.
Percentage dead in each loss group	24·3	22·7	14·2	15·7	3·8	1·3	4·1	11·6	2·3	..	13,036 dead specimens.
Eyed and alevin samples ..	77·7	10·2	3·4	4·0	1·7	0·7	1·4	0·5	0·2	0·2	422 samples.
Percentage dead in each loss group	28·5	18·4	10·1	18·8	8·0	4·6	5·0	5·0	1·0	0·6	30,080 dead specimens.

It will be seen that relatively small numbers of samples have contributed very substantially to the total losses in each category of samples. Of the total dead recovered with eyed samples, 68·3 per cent. came from 15·8 per cent. of such samples in which dead exceeded 10 per cent. While 198 samples contributed 31·7 per cent. of the dead, 4 in the 30–39·9 per cent. group contributed 21·0 per cent. of this. With the alevin samples the position is similar. Of them 31·4 per cent., with losses in excess of 10 per cent., contributed 75·7 per cent. of the total dead. While 128 of the samples contributed only 24·3 per cent. of the total dead, 11·6 per cent. came from 2 samples in the 70–79·9 per cent. group.

The treatment, as a whole, of series of data relating to different environments is open to objections, as information is lacking which would permit the weighting of data according to the relative abundance of spawning redds in different environments. At the same time, as collections represent most of the diverse types of environment New Zealand offers, and, generally, collecting was more extensive in commoner types, the following summary has some indicative value :—

Of 71,403 specimens in 120 pre-eyed samples, dead pre-eyed ova = 3,784, or 5·29 per cent.

Of 203,525 specimens in 235 eyed samples, dead pre-eyed ova = 14,444, or 7·10 per cent.; and dead eyed ova = 2,600, or 1·28 per cent.

Of 154,586 specimens in 187 alevin samples, dead pre-eyed ova = 9,800, or 6·34 per cent.; dead eyed ova = 2,851, or 1·84 per cent.; and dead alevins = 385, or 0·25 per cent.

Of the 358,111 specimens in samples which had completed pre-eyed development, dead pre-eyed ova numbered 24,244, or 6·77 per cent. The alevin samples show an eyed loss of 1·84 per cent. in conjunction with a pre-eyed loss of 6·34 per cent. Estimated on this basis there would, with a pre-eyed loss of 6·77 per cent., be an eyed loss of 1·96 per cent., thus giving a total loss to hatching of 8·73 per cent.

Dead alevins recorded comprised only 0·25 per cent. of the total specimens in alevin samples. Of such specimens, 12,651 were dead eggs and 141,935 were alevins. Of the 141,935 alevins, 385 were dead. Dead alevins were recovered with 76 of the 187 alevin samples. In each of 68 of the 76 samples, dead alevins numbered less than 10. In the other 8 samples, which contributed 201, or 52·2 per cent., of the dead, losses ranged from 10 to 79 specimens. Previously (Hobbs, 1937) the writer found no "curvatures" *i.e.*, alevins suffering from a spinal disorder and recorded only one case of an alevin suffering from yolk-sac dropsy or "blue-swelling." In the present material, live specimens included 64 cases of "curvature," which came from 25 samples. Live monstrosities numbered 49 specimens, one sample containing 18 of them. From 3 samples, 35 live specimens (31, 3, and 1) with yolk-sac dropsy were obtained. As in the digging-out of recently hatched alevins the yolks of a number are usually ruptured, other cases may have escaped notice. The infrequence of the occurrence of such cases is, however, sufficiently indicated. All three of the disorders recorded are known to cause losses, usually before completion of yolk-sac absorption. It seems reasonable to infer that disorders, which are usually mortal, and which are noticed among the live specimens, were in part responsible for the losses recorded.

Material presented in a previous paper (Hobbs, 1937) came mainly from portions of three large water-systems in a transverse section of the centre portion of the South Island — the Selwyn, the Waimakariri, and Grey systems. The Waimakariri system material included approximately 20,000 specimens from redds of quinnat salmon, a like number from redds of brown trout, and a few samples from redds of rainbow trout. Material from the other two systems came exclusively from redds of brown trout. Apart from a few other samples from elsewhere, 13 streams in three systems provided 169 samples. These comprised 73,625 specimens, of which 1,340, or 5·89 per cent., were dead. The present material comes from 64 streams comprising parts of 10 systems. Of the 429,514 specimens

from them, comprising 542 samples, 33,864, or 7·88 per cent., were dead. In all, the material comes from 77 streams comprising portions of 13 water-systems and represents a great diversity of types of environment. The 711 samples, while predominantly ones which had passed through the more vulnerable stage of development, comprise a range covering development from shortly after ova were deposited until alevins had absorbed their yolk-sacs and were preparing to emerge as free swimming fry. Of the total of 503,139 specimens recovered from the redds, dead specimens numbered 38,204, or 7·59 per cent., of the total.

LIMITATIONS OF MATERIAL AND POSSIBILITIES OF ERROR.

1. SAMPLING.

It is reiterated that the general aims of building up the collections hitherto discussed were (*a*) to make them extensive enough to be representative of the major known types of angling waters of the Otago, Southland, and Auckland districts; (*b*) as between water-systems, to make larger or smaller collections according as or not the systems carried large stocks; and (*c*) as regards any water-system, to collect from such varied areas as were offering and to endeavour to make the size of collections bear some rough relationship to the size of the spawning-areas found.

The first of these aims was substantially fulfilled. The second was only partially successful, because both weather conditions and access problems modified movement. The collection from the Kakanui system alone is disproportionately large, and that from the Wanganui system is much too small. The sizes of other collections, while not equally proportional to quantities available, satisfy substantially the aim of making collections large or small, according as much or little material was available. Regarding the third aim, sections believed to contain extensive spawning-areas were not sampled in the Mataura, Waiau, Waikato, and Wanganui. Continued turbidity limited work on the Mataura, depth of water on the Waiau, and depth together with opalescence on the Waikato. So much of the Wanganui as was seen suggested that it was sufficiently similar to the area sampled there, and to the more stable of the South Island streams, which flow over greywacke gravels.

2. COLLECTING.

Because of limitations of time, it was preferred to collect approximately all of the contents of each of a large number of redds rather than, by repeated digging, to ensure complete recovery of the contents of fewer. In collecting, the top of the net projected above the water surface. Walls of excavated material ran diagonally from either side of the net to either side of the excavation. Such walls always approached or projected above the surface. The space between the excavation and net was kept clear of coarse material behind which eggs or alevins could lodge. The passage of eggs, and especially opaque dead ones, could be observed. Such as came to rest were moved in. Especially in the case of very large redds, some escape of ova and alevins round the sides occurred. In so far as the methods tended to select, they may sometimes have favoured slightly the collection of dead eggs. Of them, those affected by *Saprolegnia* sometimes had sand particles attached which reduced any tendency towards lateral drifting. There is, however, no ground for believing that efficiencies of collection of

live and dead ova were sufficiently differentiated to affect the substantial accuracy of results. With alevin samples the possibilities of error were greater. In some cases, a proportion of the more advanced alevins could swim strongly enough to escape around the sides of the net, while dead eggs and alevins could not. Also, in a few cases of advanced samples some alevins had emerged and the dead recovered were residual from a greater quantity than were still present. The inclusion of such samples has tended to exaggerate the losses in alevin samples. However, neither the number of samples so affected nor the escapage from them was very great. The use, more particularly on some occasions, of the early spawned samples, which were most likely to have been adversely affected by superimposition, has also tended to an overstatement of losses in alevin samples. Attention has been drawn to this in appropriate places where it has seemed likely to cause a substantial error.

3. EFFICIENCY OF DEPOSITION.

Previously it has been shown (Hobbs, 1937) that brown trout satisfactorily deposited and covered in redds in one case not less than 98·5 per cent. and in another 96·5 per cent. of the eggs they were estimated to produce. The difference was less than the known difference in egg-production of trout of like size. Further, it was possible that a small loss occurred in deposition and burial or equally during excavation of the redds and recovery of their contents.

It was also shown that a female trout at a spawning might make and deposit eggs in from one to at least three different redds. The fact that the average number of specimens in a sample is usually considerably below the average quantity of ova produced by a female is not evidence of partially abortive deposition and burial.

4. EMERGENCE OF FRY FROM REDDS.

Earlier it was found that trout usually buried their eggs at an average depth below the surface of the stream-bed of about 8 in. (Hobbs, 1937). More recent observations embraced waters containing trout of a much greater average size. In redds of such fish it is usual to find eggs buried most commonly at a depth of about 10 in., and occasionally at a depth of up to 15 in. Alevins remain at the depth at which eggs are deposited until shortly before completion of yolk-sac absorption. Partly because, initially, the deposition of eggs commonly extends over several days, the emergence of alevins extends over a few days. The samples now recorded from redds include a number in which advanced alevins had already approached to within short distances of the surface, and some from redds from which a portion of the alevins had already emerged. Examination was made of six redds which still contained up to twelve live alevins each and in the immediate vicinity of which recently emerged fry were numerous. Of such redds, three were in the Kakanui, two were in the Mataura, and one was in the Makarewa. The residual dead alevins in different redds ranged in number from nil to eight specimens. The facts suggest that the great majority of alevins can escape satisfactorily from redds, when sufficiently developed.

5. ESTIMATION OF LOSS.

Dead specimens are listed as pre-eyed or eyed ova, or as alevins. The pre-eyed category includes infertile eggs. A small proportion of the total dead eggs were so decomposed, following infection by *Saprolegnia*, as to be unidentifiable as either pre-eyed or eyed. Such specimens are included with pre-eyed dead, because it seems reasonable to infer that the most decomposed eggs would normally be those which died earliest. The possibilities of eggs decomposing to an irrecoverable stage will be discussed later.

Data presented in tables give a fair indication of the extent of losses to successive points of development. The facts that there are small numbers of samples in many tables and that often small numbers of samples contribute substantially to total losses suggest that too great reliance should not be placed on computations of loss based on the data they contain. For purposes of comparison it is convenient to estimate the losses before hatching. The methods adopted are not perfect, but are such as enable data to be reduced easily to comparative form without a disproportionate sacrifice of accuracy. It is probable that errors resulting from their adoption are of less degree than others attributable to the exigencies of sampling.

Methods adopted for estimating loss introduce two possible errors. Firstly, especially in the case of more advanced samples, dead specimens may have decomposed to an irrecoverable state. The pre-eyed loss is most likely to be so affected. Secondly, the eyed-stage loss has been estimated on the assumption that the ratio of pre-eyed to eyed dead, when the pre-eyed loss is estimated from both eyed and alevin samples, would be the same as that shown by pre-eyed to eyed dead in alevin samples alone.

The possibility of eggs decomposing to an irrecoverable state is indicated by the occurrence of a proportion of very decomposed ones in certain older samples. Such eggs ruptured easily during recovery and difficulty was sometimes experienced in counting them. The osmotic properties of fertilized and unfertilized trout-eggs differ. Maintenance of osmotic equilibrium becomes increasingly difficult with age in the case of infertile eggs. Many, however, in which equilibrium is still maintained are recovered in alevin samples. For instance, in the Kakanui, infertile eggs which had maintained equilibrium amounted to 32 per cent. of dead in pre-eyed samples and 34 per cent. and 10·4 per cent. respectively of pre-eyed dead in eyed and alevin samples. The equilibrium of live fertilized eggs is easily maintained for a short period immediately following fertilization, then with difficulty until the eyed stage is approached, after which it is again very easily maintained. The very few cases encountered where osmotic equilibrium was maintained after death suggest that normally loss of equilibrium rapidly succeeds death. Before decomposition can become extensive enough to threaten disintegration of eggs, three things must happen: (1) The eggs (unless infertile) must die, (2) they must become opaque, and (3) they must become infected by *Saprolegnia*. Earlier it was shown that, even after infection, eggs are still recoverable for at least a further thirty-five days, while some were still recoverable a year later as hardened cores of yolk (Hobbs, 1937). A study of the percentages of pre-eyed dead and proportions of fungused to non-fungused ones in samples at successive growth stages is illuminating. Material from the Kakanui is especially suitable because (1) the collection is the largest from one stream; (2) temperature during incubation is very low and the incubation period is, in consequence, prolonged; (3) alevin samples are

equally from redds made early and late in the spawning seasons and therefore are not mainly those most likely to have been affected by superimposition. The percentages of pre-eyed dead recovered in pre-eyed, eyed, and alevin samples are 2·19 per cent., 3·04 per cent., and 2·71 per cent. respectively. The first figure represents losses for part of the period represented by the two latter. The decrease from the second to the third figure may possibly be attributable to decomposition. However, of the nine water-systems from which data are available, only five show this rise and fall. The other four—the Mataura and three Auckland systems—show, in alevin samples, pre-eyed dead in excess of those in eyed samples. To extents unknown (1) chance, (2) inadequacy of samples in eyed or alevin groups, and (3) (in the case of the Mataura, Waikato, and Waihou) the collection more particularly of the earlier samples to reach the alevin stage, account for this lack of consistency. Considered as a whole, data from all sources show a like fall to that in the Kakanui—a fall of from 7·10 per cent. to 6·34 per cent. in pre-eyed dead recovered with eyed and alevin samples respectively. It is clear though that, even should this fall result from decomposition, an error of like extent to it cannot result in estimations of pre-eyed loss based on both sets of material. Further, such wide differences in extents of loss between even small numbers of samples are shown in Tables XV and XVI as to suggest the advisability of basing estimates on the maximum number of samples. The proportions of total dead pre-eyed eggs affected by *Saprolegnia* to those not so affected are, in pre-eyed samples 1,126 to 2,658, in eyed samples 4,260 to 10,184, and in alevin ones 4,752 to 5,048—that is to say, 1 to 2·4, 1 to 2·4, and 1 to 1·1 in the successive groupings. It will be noted that resistance to this decomposition agent is very slowly lessened and that, even in alevin samples, over half the pre-eyed dead are still unaffected. Generally, data available do not suggest that failure to take decomposition of dead ova into account will cause errors comparable in extent to any resulting from the exigencies of sampling.

The percentage of infertile eggs cannot readily be determined where samples contain eggs which have lost osmotic equilibrium. From twenty streams, forty-eight samples were obtained in which the only dead were infertile eggs. The infertility loss per sample ranged from 0 per cent. to 3·43 per cent. These samples contained 14,998 specimens, of which 152, or 1·01 per cent., were infertile. A few cases have been mentioned where the infertility loss considerably exceeded 3·43 per cent., but these were when loss of osmotic stability precluded full determinations being made. The previous study indicated that the spread of *Saprolegnia* among pre-eyed dead was a major cause of eyed-stage losses (Hobbs, 1937). Evidence in support of this conclusion was forthcoming in the collection of the present material. Infertile eggs, because of their longer retention of osmotic equilibrium, are less subject to *Saprolegnia* infection. Because infertility losses are fairly constant from stream to stream, they constitute large or small proportions of the pre-eyed dead according as the pre-eyed losses are small or large respectively. A fractional error may be introduced through failure to make a deduction for infertility losses in estimates of eyed losses based on the assumption that the ratio of eyed to pre-eyed losses is the same in two series of samples.

It has been shown in Table XIV that there is a general tendency for eyed-stage losses to be greater where pre-eyed losses are greater—a result to be expected when the same dominant factor causes losses of pre-eyed and eyed eggs and when the spread of *Saprolegnia* among dead pre-eyed

ova adversely affects eyed ova. No constant ratio is, however, maintained between pre-eyed and eyed losses in different water-systems, a result to be expected where (1) the number of samples is not great, (2) occasionally samples show heavy infertility losses, (3) occasionally eyed samples have been affected by unusual changes, and (4) there is no reason to expect conditions everywhere to be equally favourable for *Saprolegnia* to flourish among dead eggs.

6. REMOVAL OF SPECIMENS FROM REDDS.

Obviously only such specimens as are still present are recoverable. It has been shown that the possibility of eggs rotting away is limited to a small proportion of the dead. With alevins the possibilities are far greater, but the extremely small numbers of dead found (some of which had been dead for some days) indicate that only a fractional error could result from decomposition of dead alevins. In the earlier study it was shown (and it was again apparent in making present collections) that the fauna of gravel in which redds are made comprises very largely herbivorous organisms. These flourish only in the surface inch or two of material within easy reach of the diatom covering of surface stones. The fewer carnivorous insects present frequent the surface zone, where herbivores are found. *Oligochaetes* alone were noticed at depths at which eggs were buried.

There remain for consideration two major causes of removal of specimens from redds—A, flood action, and B, superimposition.

A. FLOOD ACTION.

Necessarily samples were obtained only from such redds as could be found. With few exceptions samples came from redds which, to the trained eye, were still discernible as such. This is so even in the case of the more advanced alevin samples, which commonly were over three months old. Exceptions occurred in portions of the Aparima, Morley, and Hedgehope in one of three years in Southland. In each of these streams a few samples were obtained by digging in places where it appeared likely that redds would have been made and would later have had their surfaces levelled off by flood action. Losses resulting from the precipitation of silt in redds are reflected in foregoing tables. Consideration is limited here to the possibilities of redds being washed away, left above water-level by changes in courses of streams, or buried by the deposition of sufficient material to hide their original contours. The earlier study (Hobbs, 1937) showed that losses can be caused in these ways; but they were noticed to occur only during exceptional floods following the heaviest fall of rain in six years. Even then they resulted from landslips or from major changes in the courses of streams with wide aggrading flood-beds.

New Zealand is, geologically speaking, a youthful country. Each of the two main islands is narrow. The southern one and the southern portion of the North Island have backbones of high mountains with ranges spreading coastwards from them, separated by alluvial plains. Streams are most commonly of steep gradient. To a greater extent than in most countries stream-beds of coarse alluvium approach the coasts. Commonly, coarse gravels extend right into short tidal reaches. Not uncommonly, streams have extensive flood-beds supporting a sparse growth of vegetation on the higher, more stable portions. The Oreti and Aparima are extreme cases. Parts of the Kakanui, Mataura, and Waiau display the same

characteristics. It is especially in regard to rivers of this character that doubts have been expressed as to the ability of redds to afford protection against floods. Casual observations on such flood-beds may be very misleading if they suggest that streams just cut away their beds and banks. The chief long-term tendency of a stream is to take material from the heights and to deposit it on lower levels. The stream, while seeking sea-level, tends to level the country over which it flows. This levelling process is not something which operates evenly throughout the length of a stream. It tends, over long periods, to accomplish its object by repeatedly picking up, transporting, and dropping rock particles. Russell (1909) has stated: "It may require tens of thousands of years for a given rock fragment loosened on a mountain side to reach its final resting-place in the sea." Thus the downward passage of coarse material is accomplished in many stages, with sometimes very lengthy halts between those stages. A stream-bed comprises portions of greatly contrasting stability, and erosion at one point results in deposition lower down. While the stability of beds of different streams varies greatly, even the less stable ones have their relatively stable portions.

Fairly generally streams in New Zealand are cutting down the country at their headwaters and building up on the plains and valley flats lower down. Cotton (1922) states that, "Many New Zealand rivers are now building up the floors of valleys previously excavated, either in solid rock, as is the case of the rivers in eastern Marlborough, or in alluvium, as in the case of the large rivers of Canterbury, which, after cutting deep trenches in the gravel of the Canterbury Plain, are now proceeding to fill these up again as shown by their braided courses in convex valley bottoms . . .

"The Oreti River, in Southland, flows south-eastwards across a broad alluvium-filled depression known as the Five Rivers Plain, but instead of following the even slope of the aggraded surface across the Waimea Plain farther to the south-east, turns southwards again through a relatively narrow gap in the north-eastern end of the Hokonui Hills. The river valley through this gap is now aggraded, and the gradient of the course now followed by the river, as given by railway data, is the same as that of what was obviously a former course across the Waimea Plain. It would seem that the great depression of the Five Rivers and Waimea Plains was filled by alluvium by the stream which occupies it, until this alluvium spilled over a low col in the already maturely dissected Hokonui Hills, and that this river, wandering freely on the aggraded plains, has since followed sometimes the one outlet and sometimes the other, keeping both built up to the same gradient."

This common tendency of streams to aggrade is of importance, for it is clear that where it is operative there is no general tendency to erode, but rather a general tendency towards bed-building, with some redistribution, by erosion, of materials for this purpose.

The presence of rounded gravel in the course of a stream is not necessarily evidence that the gravel is subjected to regular movement. Very often long intervals occur between movements, and even between periods in which flowing water comes in contact with the same stones. Further, the rounding of stones in the course of a stream may have been largely the work of former larger streams. The little Waimea Stream has in parts laid bare gravels from the Oreti's former course over the Waimea Plain. Between the Hokonui Hills and the sea-coast in Southland, streams of the Makarewa sub-system and Waituna Creek and others flow over

rounded quartz gravels transported thither from a considerable distance by some former larger stream—probably the Mataura. The streams of the Inchbonnie Plain, in Westland, described earlier (Hobbs, 1937), flow over alluvial gravels of a former Teramakau River course. Often in such cases the transporting power of the present streams has been little more than sufficient to clear the accumulation of finer materials off the high points of gravels underlying the covering soil. Attempts to correlate the rates of flow of present streams with sizes of gravels deposited by former ones would be wholly unwarranted, for very often the effective resistance to increased erosion is provided by boulders of very much greater size than is necessary for such a purpose. In any case, the size alone of the boulders has only a limited significance, for it is quite possible for small stones loosely cemented in finer material to offer greater resistance than larger stones deriving less support from contiguous particles. Speight (1929) states of rivers such as the Waimakariri, in Canterbury, that, "the velocities usually accepted as competent to move gravel are not reliable when coarse material is concerned and where the bottom consists of gravel loosely consolidated to form a pavement. I have observed cases where the surface velocity of a stream has been 10 ft. per second and the stream has been running over a smooth bed made of gravel of varying size from that of peas to the size of goose-eggs and there has been no movement whatsoever of material along the bottom either by saltration or traction, and yet, under other conditions, this velocity of stream is no doubt quite competent to move pebbles the size of hen-eggs or larger."

The instance Speight discusses is by no means an isolated one. In all sixty-four streams from which collections were made for the purposes of this paper, extensive portions of the beds comprised materials to some degree consolidated or cemented. The general occurrence of this condition has not received the notice it deserves. In much that is written about development of courses of streams, attention is focused, by emphasis, on headwaters erosion and the transportation of materials brought in at higher levels, and on the transporting-powers of different velocities of water. Too little attention is directed to the results of precipitation in areas into which material is transported. Because a greater velocity is needed to start the movement of a body than is required to continue it in motion, it follows that the transportation of material, once deposited, cannot under like conditions be resumed except by water of a greater velocity. In practice like conditions do not always prevail for long, for changes in velocity and in direction of thrust of current result from added precipitation. In general, disturbance increases with rises in level, and precipitation firstly of heavier and then of lighter transported material occurs as waters recede. However, many exceptions occur in sinuous portions of streams, and it is not unusual to find flood-waters taking a more direct course which results, temporarily, in reduced flows in normal channels. Thus, at the height of a fresh, material may be deposited which may be again picked up where, with a fall in general level, there is an increase in velocity. Owens (1908) has shown that contiguous particles derive support from one another. It is important in considering the principles governing the resumption of transport of materials from beds of streams to appreciate first that earlier changes in velocity have usually resulted in the precipitation of particles of varying sizes at any point; secondly, that at any time a greater velocity is necessary to commence the transportation of a particle than the velocity which attended its deposition; thirdly, that a still greater velocity will be

needed when a particle derives support on several surfaces than in the case of a particle resting on one surface; fourthly, that, as a bed consolidates, resistance to velocity is also heightened by the reduction of the exposed areas of the particles. The principles governing consolidation of stream-beds, although fundamentally important to the reproduction of *Salmonidae* and the provision of much of their food, have received scant notice. Here it is sufficient to note that a disturbed piece of bed in a spawning-area tends to resume the character of the surrounding bed and to achieve a like degree of consolidation. The pocket of relatively loose gravel becomes progressively more consolidated and, by the springtime, can offer a much higher degree of resistance than it did earlier.

It is known that floods may cause losses in redds otherwise than through the precipitation of silt in them. Hobbs (1937) showed that losses might, under abnormal conditions, assume sufficient proportions to account for the partial failure of a year class. Other cases of adverse changes in spawning-areas through direct flood action have been since noticed. In the Mararoa River, in Southland, an extensive spawning-area under and near the Mararoa homestead bridge was changed, by the scouring-away of finer materials, to a bed of boulders too coarse for trout to spawn in. This change occurred as a result of a flood between the 1936 and 1937 spawning seasons. It is improbable that any ova or alevins remained in redds when this flood occurred, but such a flood could occur when specimens were present. As is usual at bridge-sites, the river here is very confined and a considerable rise is necessary before flood-waters can spread. In the summer of 1936–37 considerable modifications of bed, which tended to reduce the extent of spawning-ground available for the next season, took place in the Omohine Stream. Fry had emerged some months before this flood. The modifications of this bed resulted, in part, from a redistribution of materials by flood-waters, following the removal of most of the coarser boulders to be crushed for road-construction purposes.

The extent of losses caused by direct flood action can only be determined satisfactorily by regular observations made over a series of years. The general tenor of such information as is available is to suggest that in many streams the chances of flood loss are very remote, while in others, while losses occur, they do so only at irregular intervals. Evidence which has led to these conclusions is as follows :—

(1) Alevin samples were collected from thirty-eight of the sixty-four streams. The remaining twenty-six were nearly all minor ones from which the collection of alevin samples was not attempted. In thirty-five of the thirty-eight streams the surface contours of all redds from which alevins were obtained were still sufficiently preserved to enable their ready identification. This was the case with most of the redds in the other three streams. In these three streams samples were obtained also from a normal depth below the surface, where contours were no longer preserved. While it is the case that only redds still extant would be found, the writer's general impression is that, even when alevins were approaching the time of emergence, samples could still be located in practically all places where previous experience had shown that fish could be expected to spawn. The number of redds which could still be located and the extent of utilization of suitable areas were

commonly such that it was difficult to believe that any considerable additional number, no longer discernible, could previously have existed.

(2) Generally, of such streams confined to one channel as were revisited, it was the case that the surface contours of many redds were sufficiently preserved to enable them to be identified at the beginning of the next succeeding spawning season. This was also the case with such redds as were reinspected in portions of the Oreti, Aparima, and Kakanui, although each of these streams has a braided course over a bed, in parts, subject to much movement.

(3) All streams comprise reaches of contrasting stability of bed. Over considerable lengths there may be a general aggrading tendency or a degrading tendency. But neither tendency is uniformly manifest in either type of area, and, in each, portions are relatively stable often for numbers of years. Relatively stable portions, while occurring more commonly in the broader valley and plains sections of streams, are found at irregular distances along the whole courses of most streams.

(4) An overwhelming majority of fish select stable portions of bed, where material of suitable size is loosely cemented or consolidated with an admixture of finer materials. In such relatively stable portions, eggs are usually buried at from 8 in. to 10 in. below the surface. The stability of such portions of bed is commonly evidenced by (1) a considerable degree of cementation of bed material, although not necessarily of the immediate surface stones; (2) a good diatom growth. Such a type of bed, in streams given to severe flooding, is commonly found where low banks enable flood-waters to spread and, also, where evidence of recent lateral erosion is usually lacking. Lack of appreciation of the fact that trout select relatively stable portions of stream-beds accounts largely for the fears of anglers as to the safety of naturally spawned eggs. Commonly, the requisite degree of stability is offered by small tributary streams. In streams with wide shingle flood-beds, a substantial proportion of the fish utilize the beds of minor off-shooting streams and the short creeks, fed by percolating waters, so common in such beds. Those spawning in the main channel commonly seek positions in the lateral diatom zones.

(5) Fish were observed to make redds more during freshes than at other times. Further, many redds are made in places to which access would be difficult except when streams are above normal level. Again, while in non-flooding streams redds are always parallel to the direction of flow, and elsewhere most redds are made in places where there is no pronounced change of direction of flow during freshes, a proportion of redds found after subsidence of waters were parallel to the flood line rather than to the normal direction of flow. The movement of gravel in redd-construction results from the efforts of the fish with some assistance from the current. If, later, water alone is to undo the work performed by fish and current, some increase in velocity over that shown in the earlier fresh will be necessary.

(6) Under direction, co-operatives of the Southland Acclimatization Society kept sample series of redds under observation in 1937 and again in 1938. Wooden pegs were driven to a depth of about 10 in. into the bed round each redd. Tops of the pegs protruded about 2 in. from the bed. Each redd selected was one of a series in that vicinity. Streams chosen for this test of effects of floods were ones with relatively loose shingle beds, where the possibilities of damage occurring seemed greater than in most streams.

There were marked in 1937 over a ten-mile length of the Oreti, eight redds; in eight miles of the Aparima, eight redds; in nineteen miles of the Eglinton, ten redds; and in one mile of the Upukerora, six redds. Later examination of marked redds showed that in all cases except one in the Eglinton no substantial modifications by flood action had occurred before fry emerge. In regard to the case excepted, doubt is expressed by the co-operative concerned as to whether he searched in the right place. The winter and spring of 1937 were exceptionally fine and freshes were fewer and more moderate than usual.

In 1938, when conditions were more normal, twelve redds, spaced over a greater distance in the Oreti, were marked. These remained substantially unchanged by floods until March, 1939—many months after fry would have emerged—when one of the sites was washed out. Although no further redds were marked in the Aparima in 1938, reinspection then and again in March, 1939, of pegs used to mark redds in 1937 showed the pegs to be still in position.

General observations suggest that stocks vary in density largely in accordance with the extent of suitable spawning-bed offering. It has been stated that trout select relatively stable areas for purposes of reproduction and avoid large areas of unstable bed. In so far as floods render areas unstable, they limit the extent of the bed in which trout will spawn. It is probably in this manner, rather than by their direct action on spawning-areas, that floods are of most significance in regard to reproduction. It would seem that in the spawning-areas eggs are so placed as to ensure them a considerable margin of safety from normal flood effects, but a margin not sufficiently great to protect all from the effects of abnormal floods.

B. SUPERIMPOSITION.

The conditions trout require for spawning are very special: the extent of the areas offering such conditions is limited: rather than spawn in unsuitable places, later spawners will use sites previously used by earlier spawners: losses, the extents of which, in so far as they result from displacement of eggs, have not been measured, may result from superimposition.

Spawning Requirements.

To be used for making redds, commonly a bed must conform to certain requirements as regards (1) size of stones, (2) degree of consolidation, and (3) gradient. As regards any one of these three points some range of tolerance is exhibited. Rarely are aberrant cases encountered which fall

outside the usual ranges of tolerance, but cases have been sometimes noticed in lake tributaries under circumstances suggesting it as possible that contemporaneous occupation by other fish of all suitable sites had influenced a few fish to choose abnormal positions. Trial redds in which extremely few, if any, eggs have been placed are found in most streams.

(1) Because redds are made in gravels of soft or hard sedimentary rocks, or pumice, rhyolite, quartz, granite, or mica-schist, the nature of rock appears to be of no significance in influencing choice. The disintegration of some rocks is, however, more given to the production of suitable gravels than that of others. Commonly, for instance, in New Zealand neither the softest sedimentary rocks nor limestone produce a large quantity of suitable gravels. Schist, granite, and rhyolite are reduced to sand after very little transportation. Greywacke, on the other hand, is ideal, in that it ruptures into particles which round to suitable size and are resistant enough to bear transportation well and provide extensive gravel beds.

The dominant surface stones in gravels used for spawning are commonly of about 2 in. in diameter, but vary from 1 in. to 3 in. Large trout show a tendency to spawn in coarser material than do small fish, but may also use material of a size used by any smaller trout. Very rarely are the stated size limits exceeded in New Zealand. The degree of rounding attained by gravels has apparently little importance. Most commonly redds are made in rounded gravels, but only because such gravels predominate in places in other respects suitable. Angular stones, but not very sharp-edged angular stones, were observed to be used.

(2) Trout do not spawn in loose clean gravel, but in gravel admixed with finer materials and to some extent consolidated. The state of the immediate surface material, rather than of the underlying material, decides whether or not the area will be avoided because of excessive consolidation. It is a general rule, to which very few exceptions occur, that trout will not spawn where immediate surface stones are partially embedded in and cemented to underlying materials. Where surface stones sit "waist deep" in finer materials and the whole is consolidated, trout do not spawn. Most commonly sites are selected where relatively loose stones overlie, to a shallow depth, a more consolidated bed—that is to say, relative looseness of surface stones is necessary before a redd will be commenced, and relative consolidation is necessary if the redd is to be proceeded with and eggs are to be deposited. The stability of the relatively loose surface stones is usually indicated by a good diatom growth on them. The extent of the consolidation of the underlying material is often so great as to provoke surprise that fish could dig in it, and sometimes so great that only visual evidence will satisfy an observer that they have done so. Although it is not a usual occurrence, except where superimposition takes place, trout will sometimes dig through as great a depth of loose material as 10 in. to reach and deposit eggs in sufficiently consolidated underlying material. In the Raparapa in a few cases eggs were found buried under such circumstances at 12 in. to 14 in. down, while short distances away in the same stream eggs were buried at usual depths where a consolidated bed was more quickly encountered. Where direct superimposition, rather than the more common slight overlapping, takes place, it seems reasonable to expect achievement of a greater depth than before, with resultant loss of earlier eggs. In 1934,

in the Selwyn River, it was observable, against pegs driven into the bed, that gravel was loosened to progressively greater depths as superimposition became marked enough to bring about a wave-like contour of parts of the bed. The fact of later spawners using material already loosened is not at variance with the fact that, normally, relative stability of bed is an essential requirement for oviposition. Later spawners, denied the wider range of choice of earlier spawners, confirm the earlier selection of sites because of suitability of size of gravel and gradient, and tend to satisfy their third requirement, of stability, by digging deeper.

(3) Of material not objectionable on the ground of size or instability, much is avoided because of unsuitable gradient. The gradient is suitable where the bed falls but slightly, or is approximately level, or (and most commonly) where it rises slightly in the direction of flow. Redds are not commonly made where the bed is falling, but may be made in such places if the fall is so slight that a mound can be thrown up, which will give the bed at that spot a rising tendency. At right angles to the current the bed must also be approximately level, and portions of bed, otherwise suitable, but showing moderate to steep lateral inclines, are usually avoided.

Extent of Suitable Areas.

Suitable areas are found only in the gravel reaches of streams. In New Zealand streams the greater part of the gravel is either (1) too coarse, or (2) too fine, or (3) a mixture of very fine and very coarse material lacking sufficient of intermediate sizes, or again it is (4) too loose, or (5) has too consolidated a surface: material objectionable on none of these grounds commonly lacks suitable gradient.

In 1936 an inspection was made of some twenty miles of the Kakanui River. Records were kept of all redds found, whether isolated or grouped, and from ascertained areas of groups and of a sample series of redds the total occupied area was estimated. A rough estimate of the total area of stream-bed examined was made. The Kakanui has, generally, a gravel and boulder bed averaging 40 ft. in width in the twenty miles of water from the short tidal reaches up. Bed-rock occurs very rarely, and *Elodea canadensis* is rooted in silt, which beds a few deep holes and comprises but a fractional part of the total area of bed. The estimated area of spawning-beds observed in relation to total area of stream-bed suggests that the former occupy only about 0·15 per cent. of the total. Yet the Kakanui appears, by general New Zealand standards, to be fairly well provided with spawning-grounds. Had a suitable type of bed of such extent existed, the whole of the redds in twenty miles of river could have fitted into a $54\frac{3}{8}$ yard length of it.

Degrees and Effects of Superimposition.

It is convenient to consider, under two heads, evidence of losses resulting from the superimposition or congestion of redds:—

(*a*) Cases where destruction is effected without removal of specimens from redds.

(*b*) Cases where destruction results from removal.

(a) Superimposition Losses without Displacement.

Most commonly cases of this kind result from the displacement, on to older redds, of material loosened in the construction of newer ones, or from the diversion of current from older redds by the construction of redds in front of them. Sometimes, where direct superimposition occurs, eggs are disturbed and killed, but the current is insufficient to remove them from the redd. Specimens affected adversely in any of these ways were recovered with the apparatus used and are included in the dead already shown in tables.

Of the 542 samples collected, 107 showed losses of 10 per cent. or more. Such losses, in samples in the eyed-ova and alevin groups, comprised 68·3 per cent. and 75·7 per cent. respectively of total dead recovered (*vide* Table XVI). Of the 107 samples, 3 were taken under circumstances which made the noting of attendant conditions impossible. A further 18 were from Waituna Creek, where the congestion of redds contributed to losses, but causes have not been noted against particular cases. As regards the remaining 86 samples, from examination of attendant circumstances it has been considered safe in 35 cases (specifically mentioned earlier) to regard superimposition, or conditions consequent on congestion of redds, as mainly responsible for the heavy losses. Many of the other 51 samples came from congested spawning-areas, and, while the same causes may have contributed to losses, evidence was too inconclusive to warrant an expression of opinion as to whether or not they appeared to be mainly responsible. Adverse conditions, giving rise to heavy losses found, appeared to be mainly the consequence of congestion of redds in a proportion, thus estimated at 41 per cent., of such cases as were studied individually.

Of the total 542 samples, 211 came from separate redds and the balance of 331 from congested redds. A study of the proportion of samples showing heavy loss in each of these groups should, although based on partially different data, afford some indication of the soundness of the field diagnoses of causes of loss just discussed. The separate redds yielded 27 samples with heavy loss and the contiguous redds 80. These numbers constituted approximately 13 per cent. and 24 per cent. respectively of the separate and contiguous redds. Had all 542 samples shown losses of the same order as those shown by separate redds, there would have been about 70 cases of heavy loss or 37 (35 per cent.) less than were found. For the following reasons, present data are unlikely to afford an accurate measure of losses resulting from superimposition. A sufficient number of samples from both separate and contiguous redds in a reasonably uniform area where enough heavy losses occurred is lacking. Consequently, it has been necessary to treat as a whole material from dissimilar areas where, further, the relationship of the proportion of redds superimposed to the proportion showing heavy loss is far from constant.

The fact, however, that results similar in general tenor have been obtained by different approaches to the same problem justifies the conclusion that a substantial but indeterminate proportion of the dead in samples collected result from the congestion of redds.

(b) Superimposition Losses with Displacement.

Because eggs are concentrated in one or more small pockets, excavated to below average depth in the larger excavation and occupying only a fractional part of it, some measure of overlapping of redds without

displacement of eggs spawned earlier is possible. In a typical one of a series of redds left above water-level in the Selwyn River, examination showed eggs concentrated in four pockets, possessing a combined area of about 100 square inches, in a larger excavated area of about 4,320 square inches. The chances of disturbance of earlier eggs are further lessened by the usual practice of a later spawner of commencing the construction of its redd some little distance in front of the point of commencement of the earlier redd. Very commonly, although not invariably, where superimposition has occurred the more recent samples are located upstream from the older ones. Examination of thirteen separate redds in the Selwyn River, in Canterbury, showed distances of from $1\frac{3}{4}$ ft. to $8\frac{3}{4}$ ft. (in the average case, 3·4 ft.) between the most upstream pockets and points of termination of the excavations. Thus, this much of the forward end of redds could have been redug without displacing earlier ova.

In three separate redds of brown trout selected at random the size of redd bore approximately the same relationship to the number of eggs deposited. The redds were approximately 41·6, 31·2, and 22·5 square feet in extent. On the basis of the average number of ova per square inch of total area excavated, they showed depositions of 0·340, 0·329, and 0·336 respectively. Such depositions may be considerably exceeded where superimposition occurs. Reference was made previously (Hobbs, 1937) to two small self-contained spawning-areas of 42 square feet and of 62 square feet in two Westland streams of the Poerua and Orangipuku sub-systems of the Grey River system. These showed, over their whole areas, average depositions of 1·09 and 0·51 specimens per square inch. Stomach contents of eight out of twelve trout killed on these and adjacent spawning areas, while late fish were still working, included eggs containing well-developed embryos. The number of eggs so recovered ranged from ten to fifty-three per specimen. Such eggs had been dislodged by spawning fish and not by flood action. When spawning was completed, there were recovered from the smaller area 2 pre-eyed samples averaging 917 specimens each, 7 eyed samples averaging 479 specimens, and 2 alevin samples averaging 336 specimens. The respective figures for the larger and less used area in the other stream were 2, 380; 16, 435; and 4, 219. Comparative data from isolated redds in these two streams are lacking. The small average size of alevin samples from these waters, where there is a general tendency for larger fish to spawn earlier, is very suggestive. Neither the effective deposition rates of 1·09 and 0·51 specimens per square inch recorded from these two waters where superimposition losses are known to have occurred, nor the proportions of samples taken from superimposed or overlapped redds in them—namely, 78·6 per cent. and 61·1 per cent. respectively—are remarkable. Data on effective depositions in other streams relate to one or two small groups of redds in each. While of very limited comparative value, they suggest that fairly commonly eggs may be as densely concentrated as they are where it has been established that superimposition losses occur. These data are as follows: Kakanui River, 0·50 and 1·35; Morley Stream (Waiau System), 1·02; Flaxy Creek (Oreti System), 0·98; Waituna Creek, 0·55; and Selwyn River, 1·19 and 0·56. Deposits in excess of this may, of course, be shown if portions only of redds, superimposed or not, be studied. General impressions resulting from digging of redds in many waters are that depositions as heavy as those stated occur commonly in superimposed spawning-areas in New Zealand.

Records of the proportion of redds, either wholly or partially superimposed on or overlapped by others, in certain streams are given in Table XVII :—

TABLE XVII.

River-system.	Stream.	Superimposed or Overlapped Redds.	Total Redds.
Kakanui : Total	..	47, or 75·8 per cent.	62
Waiau	Waiau	7, „ 70·0 „	10
„	Eglinton	11, „ 78·6 „	14
.. .. ..	Upukerora	9, „ 75·0 „	12
.. ..	Mararoa	2, „ 40·0 „	5
„	Wairaki	4, „ 44·4 „	9
.. .. ..	Orawia	28, „ 87·5 „	32
„	Sundry tributaries ..	5, „ 55·6 „	9
„ : Total	..	66, „ 72·5 „	91
Aparima : Total	..	15, „ 34·9 „	43
Oreti	Oreti	21, „ 65·6 „	32
„	Makarewa	26, „ 81·2 „	32
„	Sundry tributaries ..	33, „ 68·7 „	48
.. : Total	..	80, „ 71·4 „	112
Waituna : Total	..	25, „ 89·3 „	28
Mataura	Mataura	6, „ 35·3 „	17
„	Sundry tributaries ..	28, „ 54·9 „	51
„ : Total	..	34, „ 50·0 „	68
Waihou	Waihou and tributaries	17, „ 77·3 „	22
„	Waiomou branch ..	4, „ 16·7 „	24
„ : Total	..	21, „ 45·7 „	46
Waikato	Sundry tributaries ..	18, „ 72·0 „	25
„	Waipa branch ..	14, „ 31·1 „	45
„ : Total	..	32, „ 45·7 „	70
Wanganui : Total ..	..	9, „ 69·2 „	13
Awakino : Total	..	2, „ 22·2 „	9
Grand totals ..	..	331, or 63·2 per cent.	524

The comparative value of these determinations is limited because, when they were made, some trout were still spawning in the Waiau, Eglinton, Upukerora, and Orawia (Waiau system), and in the Waipa (Waikato system), and the Waihou. They are. however, sufficient to show that overlapping of redds, to degrees approaching and comparable with those shown, where removal of ova resulted, is usual in streams examined. This form of presentation of data may overemphasize possibilities of loss unless it is appreciated that only the contents of earlier redds made were endangered and that degrees of overlapping varied.

The data which follow, while too meagre to be conclusive in themselves, are not inconsistent with evidence adduced earlier of removal of specimens from redds. In the 1936 survey of the Kakanui spawning-areas there were found 326 of what appeared, without further examination, to be separate redds. Every twentieth of such apparent redds encountered was dug. Of the sixteen samples obtained, eight only were from separate redds. Each of the remaining eight was the work of two or more females which had spawned at different times. From these latter eight no fewer than twenty-one separate samples were obtained and in each case the surface contours of only the last redd made were clearly apparent. In Table XVIII are shown the sizes of samples from separate and from superimposed redds and the average size of pre-eyed and of older samples in each group. In the table, samples from superimposed redds are arranged from left to right in ascending order of development.

TABLE XVIII.

	Size of Samples.	
	Pre-eyed.	Eyed and Alevin.
Separate Redds.		
No. 1	73	..
No. 2	348	..
No. 3	1,513	..
No. 4	..	971
No. 5	..	1,708
No. 6	..	2,024
No. 7	..	854
No. 8	..	1,198
Superimposed Redds.		
No. 1	195, 535	472, 50, 352
No. 2	277, 224	557
No. 3	..	251, 665
No. 4	206	745
No. 5	367, 2,067	1,615, 1,145
No. 6	584	2,660
No. 7	..	293, 191
No. 8	..	22, 1,300
Average Sample.		
Separate redds	645	1,351
Superimposed redds	557	737

It will be noted that both groups show smaller average pre-eyed samples than older samples. The explanation is probably that smaller trout spawn later and deposit fewer eggs per redd. Observations made in Westland in 1934 showed that the average size of females fell as the spawning season progressed. The mean number of specimens in pre-eyed samples from superimposed redds is slightly less than that in similar samples from separate ones. A marked increase with age in the disparity between mean sizes of samples in the two groups is shown, however. In order to determine the significance of the differences observed between the mean size of samples from separate and contiguous redds, the *t*-test (Fisher, 1936) has been applied to the results. From this it appears that the probabilities of these differences being due only to random sampling are approximately 0·85 for the pre-eyed samples and 0·15 for eyed and alevin samples. Thus the former difference is definitely without significance, but the latter may possibly be significant. The 8 separate redds together contained 8,089 specimens, an average of 1,011 each. The 22 samples from superimposed redds contained 14,773 specimens, an average of 672 each. Altogether the 30 samples contained 22,862 specimens—that is, 7,468, or 25 per cent., less than if all had contained as many specimens each as the separate redds did. It is known that fish commonly make several redds at a spawning and deposit varying numbers of eggs in each. Without more adequate data and a better knowledge of the factors determining the number of eggs to be shed at one point and the possible influence of prior use of a site in the making of such determinations, it would be hazardous to estimate superimposition losses. Present data suggest, however, that the proportion of eggs dislodged during superimposition may be appreciable. They are, however, insufficient to establish this conclusively.

Evidence that superimposition of redds is a common condition in New Zealand waters has been given. Evidence that losses result from it may be summarized as follows :—

(1) It was judged in the field from examination of attendant circumstances that in the case of a substantial proportion of samples collected the conditions apparently responsible for heavy losses resulted from congestion of redds.

(2) These impressions were confirmed subsequently by an analysis of cases showing heavy loss which established that such cases were much more frequently encountered in contiguous redds than in separate ones.

(3) The recovery from the stomachs of trout in certain waters of eggs containing well-developed embryos, at times when superimposition was occurring while streams were at normal levels, afforded evidence of further losses, additional to those shown in collections. The occurrence is shown in most waters of superimposition to degrees approaching or comparable with those found where these additional losses took place.

(4) Comparison of size of samples from separate and contiguous redds showed older samples in the latter to be markedly smaller. Data on this point, while too meagre to be conclusive, suggest that the proportion of earlier eggs dislodged by spawners and not recovered by present methods of sampling may be substantial.

THE SIGNIFICANCE OF SUPERIMPOSITION.

1. THE OCCURRENCE OF SUPERIMPOSITION.

There are certain difficulties in attempting a consideration of the biological significance of superimposition by reference to data relating to wild stocks which, on the one hand, are exploited by man and which, on the other, have their sizes altered by artificial transfers. The stocks of all the waters discussed in this paper are in varying degrees exploited by man. Many, too, have additions of unknown relative extent made to them by transfers of stock. However, superimposition occurs very generally in certain Westland waters, where it has been stated (Hobbs, 1937) that no liberations of brown trout (the only exotic species known to be established in them) have been made for thirty years. In Waituna Creek a similar condition obtains. It occurs, too, in the Eglinton, Upukerora, and Selwyn Rivers, which are among the main sources of supply of eggs for New Zealand hatcheries, and to which only very small portions of the young hatched from eggs taken are returned. The Mangawhero sub-system of the Wangaehu (above a waterfall) affords another instance of natural development of a stock to a point where heavy superimposition takes place.* That is to say, as regards these waters at least, it seems inevitable that cessation of interference with stocks by man could only increase the present degree of superimposition.

* Superimposition of redds of brown trout was observed in the Mangawhero in 1939. No brown trout have been liberated there since 1919. Rainbow trout, formerly the dominant species, are now rarely found, and attempts to aid the stock by liberations have failed to arrest this decline over a period during which the stock of brown trout has expanded naturally.

Superimposition is shown to occur generally in other waters discussed in this paper. Whether or not it would continue to do so if interference with stocks by man ceased is doubtful, unless it can be shown that man's additions are insufficient to balance man's abstractions. It is the belief of most experienced New Zealand anglers—a belief supported, as regards certain waters, by evidence produced by Percival (1932)—that the average angler now catches less fish of mature sizes than he did thirty to forty years ago and that the average size of the fish caught has fallen. The number of anglers is now greater and the liberations of young fish per angler have increased. Percival's data on these two points for the Southland District typify what has been a fairly general trend in New Zealand. The evidence, such as it is, suggests that man's additions have commonly been insufficient to balance abstractions, and therefore that if interference ceased, populations would tend to stabilize at higher levels with heavier degrees of superimposition.

Frustration, through insufficiency of spawning-ground, of an ability to increase is not a new condition in New Zealand. Arthur (1883) recorded an instance of "numerous spawning fish turning up the same redds successively." This was in Butel's Creek—a tributary of Lake Hayes—where Arthur states that brown trout was first liberated in 1874. At that time it was unusual for a liberation in any water to exceed a few hundred fry or small fingerlings. This suggests an extremely rapid development of a stock to a point where the holding-capacity of spawning-areas was being severely taxed. Between 1870 and 1885 brown trout were liberated in most of the more accessible river-systems in the country, and the species was recorded by Spackman (1892) as being widely established.

In the European and American waters to which brown and rainbow trout respectively are native, the spawning of later fish in sites used earlier by other fish has been noticed by various writers.

2. NATURAL REGULATION OF POPULATIONS.

Because modern fisheries science owes its existence largely to the depletion of stocks by man, attention has been focused on depleted stocks, and the question of what, in pre-depletion times regulated the density of populations has received little notice. In one of a series of essays on populations by Hjort and others (1933), Ottestad (1933) has stated that, "Even the earliest attempts to cultivate unicellular organisms showed that ideal growth (Malthus's geometrical ratio) does not take place in Nature or under experimental conditions where the supply of food is adequate—as Liebig demonstrated in his celebrated law of minimum factors (those which only exist in a minimum quantity)—or where the limits of space check expansion or poisonous metabolic products check growth. Any one of these factors induces a course of growth, the graphic representation of which takes the shape of a sigmoid curve. This sigmoid curve is found to be characteristic of the natural growth of polycellular organisms, cells, embryonic stages, and populations."

The effect on growth of populations of factors which tend to produce a state of parity between births, or survivals, and deaths, once a population has passed a certain point, is understood. The precise nature and mode of operation of such factors is still a matter for conjecture in the case of populations of most kinds. Elton (1927) states that, "The regulation of numbers of most animals would appear to take place along the following

lines: Each species has certain hereditary powers of increase which are more or less fixed in amount for any particular conditions. It is usually also kept down in numbers by factors which affect breeding—*e.g.*, lack of breeding-sites, &c. It is further controlled by its enemies, and if these fail, by starvation." Nicholson (1937) states, "While almost all factors in the physical and biotic environments of an animal may exercise some influence on its population density, competition is the only factor capable of regulating or governing populations. Were it not for competition, population densities would be completely indeterminate, and so there would be no regulated densities for other environmental factors to modify. The study of the physical environment helps to explain increases and decreases in population densities, but, by itself, it gives no information whatever about the actual densities animals will maintain under given conditions. In order to understand why any animal has a particular density when subject to particular conditions in the field, we must have a detailed knowledge of how competition influences the species." Nicholson uses the word "competition" in a wider sense than is usual. In speaking of the necessary properties of factors capable of producing a state of balance, he says, "It is absolutely essential that the intensity of action of such factors should vary when there is population change, and vary in such a way as to cause the density of a population to tend to return to its position of balance. That is to say, the action of the controlling or balancing factor must become more severe when the population increases, and less severe when the population density decreases."

3. NATURAL REGULATION OF POPULATIONS OF TROUT.

Many factors, both physical and biotic, affect the density of a population of trout. Fluctuations in density result both from the direct action of physical factors—*e.g.*, floods and droughts—and indirectly from consequent changes in the relationship of a population to its biotic environment. The varying stresses of physical factors cause deviations from the mean of population strength. In contrast with these are such biotic factors as govern densities of populations by tending always to compel a return to a state of balance. Factors of the first type cannot condition the intensity of their action to the size of the population. These are likely to affect similar proportions of the components of a population, no matter what its density is. Factors of the second type affect different proportions at different densities. Factors which affect adversely an increasing proportion of the components as a population tends to increase possess the essential quality of controlling factors. Environments may be so unsuitable, physically or chemically, that they will not carry a self-supporting stock of trout. Where such conditions fall sufficiently within the range of tolerance of trout—that is to say, wherever natural populations exist—it is necessary to study the relationship of a population to its food-supply, its breeding-sites, and its natural enemies to learn how its density is controlled. While all three are important potential controlling factors, the question of whether one or more (and, if one, which) will be operative in any particular case will depend on the time, in relation to population development, at which any becomes operative. Food resources, spawning-grounds, and enemies may be associated in different proportions in the environments of different populations of trout. Competition for either of the first two, or a sufficient change in the proportion

of enemies to area over which they operate effectively, might, it would seem, first become operative in different cases. It is possible to proceed some distance in a consideration of which of these potential governing factors actually becomes operative in New Zealand.

Spawning-grounds as a Controlling Factor.

The utilization of spawning-areas by a stock of trout at different known densities has not been studied. However, what would happen may be learnt from a study of spawning-areas as increasing proportions of the population use them in one season. Observations show that, while for a time females select unused sites, later, superimposition commences and thereafter increases in degree. It has been shown that losses result both from the displacement of eggs and, less directly, from the lodgment in other redds of materials disturbed in the construction of newer ones. Thus the efficiency of reproduction, in so far as it is affected by competition for spawning-ground, is high and constant when the population is at lower levels, but becomes progressively lower as the population develops beyond a certain point.

The condition was observed to occur in the spawning-areas of all stocks so far discussed. It is known that a number of these stocks are self-supporting. As regards the others the position is less clear, but such evidence as is available is not at variance with the view that superimposition of still greater extent is likely to occur if man ceases to interfere with them.

Food as a Controlling Factor.

Lack of food could limit the size of populations by causing starvation or by inducing cannibalism. Again, it could act less directly by reducing the growth rate of individuals and by lowering their fecundity. Whether these or other effects of competition for food become operative is less certain than that they would do so if nothing else arrested the development of a population earlier. Food need not necessarily be an important factor in regulating the size of populations of fish. Hjort and others (1933) state that in the case of Norwegian herrings the margin of food-supply over needs is so great that violent fluctuations in abundance of year classes are not accompanied by significant changes in their growth rates. Different populations of brown trout may display wide differences in rates of growth and in size at first maturity. So marked are the differences of growth in various environments that Dahl (1917) likened them to those displayed by some plants when subjected to contrasting conditions. Thus it would appear that the extent of food resources might have a marked influence on the size of individual trout without starvation or cannibalism necessarily being induced—that is to say, while starvation or cannibalism, if commonplace, might indicate that population density was being regulated by want of food, their absence would not exclude the possibility of regulation through effect on the size of components. Data relating to the two former possible modes of regulation will be considered first.

Examination of the gut contents of 793 small brown trout (all of less than 20 cm. and mostly of below 10 cm.) showed only 3 with smaller trout in them. The material used came from nineteen different streams and included much collected throughout the year, from waters at Inchbonnie, in which very dense massing of redds occurs. Hudson (1904), Stokell (1928 and 1936), Parrott (1929), and Phillips (1929), in records of the examination of 550

stomachs of large brown trout from different waters, do not record the recovery of any smaller ones. Cannibalism appears to be an exceptional happening among brown trout in New Zealand. Such a conclusion is consistent with that of Frost (1939) about certain Irish waters and of André (1935, 1936, and 1938) about certain European waters. The facts that all the 793 small trout were moderately well proportioned and that identifiable food organisms were absent from the stomachs of only 10 specimens (all of which had fed a little earlier) do not suggest any likelihood of losses occurring through starvation.

The question remains as to whether lack of food regulates population density in the less direct way—that is, by restricting the growth rate and fecundity of individuals. It will be noted first, that superimposition was found in spawning-areas in all streams examined. The extent of spawning-areas in relation to food-supply must have varied from environment to environment. Yet no case was encountered where the food resources were sufficiently limited to stop the development of a population before it commenced to make excessive use of the spawning-areas. Therefore, if want of food had any marked influence on population density, its effect must have been a contributory one to that of superimposition. If lack of spawning-ground alone stops development, an excess of food should be present and growth of individuals should, in the average case, be good. Conversely, if food alone regulates density, the stress on the spawning-areas should be lighter and growth should be poor. If lack of food contributes substantially to the regulation of density, then data relating to a sufficient number of populations should show that, in the average case, when growth is poor superimposition is lighter. Data are available which throw light on growth rates and intensities of superimposition in certain waters.

Parrott (unpublished manuscript) compares rates of growth of brown trout in certain waters, during their first five years of life, with standards of growth arrived at from the study of some thousands of specimens from many New Zealand waters. Included in this study are data relating to rates of growth in four river-systems in which redds were examined for the purposes of this paper and three in which redds were examined earlier (*vide* Hobbs, 1937). Growth rates are expressed as averages of percentages above or below the New Zealand standards for each of the first five annual increments in lengths. So expressed, growth rates, together with data relating to intensity of spawning, are shown in Table XIX :—

Table XIX.

River-system.	Growth Rate.	Percentage of Redds contiguous or overlapped.	Efficient Deposition of Ova per Square Inch in different Sample Plots.
Selwyn	+ 6·1	..	0·87 (1·19 ; 0·56)
Kakanui	+ 2·1	75·8	0·92 (1·35 ; 0·50)
Aparima	+ 2·1	34·9	..
Waiau	+ 0·2	72·5 + (spawning incomplete)	1·02
Poerua	— 0·9	78·6	1·09
Oreti	— 1·3	71·4	0·98
Orangipuku	— 8·1	61·1	0·51

Little significance attaches to data on depositions per unit area in the few small sample plots. They are included only because more satisfactory data on the proportion of contiguous redds are not available from the Selwyn River. It is apparent from the table that heavy superimposition may be found both where trout grow well and poorly. Generally this condition is not shown to be less pronounced where trout grow poorly, and therefore the data do not indicate that the density of these populations is affected by lack of food.

Because of the possibility of factors other than the mere quantity of food influencing growth, too much importance should not be attached to conclusions indicated by data relating to so few streams. So far as it goes, however, available evidence suggests that commonly populations develop until checked by lack of further spawning-grounds rather than by lack of food.

Predators as a Controlling Factor.

The role of natural enemies in the regulation of density of populations has been discussed by Nicholson (1937), who states, "Where the population of an animal is greatly decreased, there follows a corresponding reduction in the density of their enemies which are dependent upon this species. The natural enemies in their reduced numbers can consequently search effectively over only a smaller proportion of the area they were originally able to search. This means that only a smaller proportion of the host species is found and attacked by natural enemies—consequently, the host individuals have an increased chance of survival." Parasitism, or at least a very considerable degree of dependence of the inimical species on the other, would be necessary in a case where regulation, in the manner described by Nicholson, was possible. Stokell (1936), who considers the effects of parasitism on trout in certain New Zealand waters, offers no evidence of resultant deaths or lowering of fecundity.

Regulation of density by enemies appears to be equally possible in other ways, where the extent of dependence may be by no means so great. For instance, it is possible for predatory birds, given to feeding in both salt and fresh water, to ignore, for the time being, a type of environment where the usual prey has suffered a reduction in population density. Thus the intensity of attack by a predator (and especially one possessing better motive power than its prey) might intensify or diminish with population changes of the prey. Again, where two species of carnivorous fish feed largely on the same food and one is better equipped to prey on the other, it seems possible that, with increase of the weaker species, competition for food might result in a larger proportion of the prey species being attacked—that is to say, the proportionate effect of predatism might increase with increase of prey.

Despite natural enemies, trout increased rapidly in numbers following their first liberation in New Zealand in 1868. The early development of the Lake Hayes stock has been mentioned. Among other cases, Arthur (1878) describes the Lee Stream, in Otago, as having developed a stock throughout a course of twenty miles by 1878 from a single liberation of ninety-eight young fish in 1869. The same writer (1883) speaks of depredations of bullies (*Gobiomorphus* sp.) and of cormorants (*Phalacrocorax* sp.) and records the general occurrence of the latter in inland waters. Sherrin (1886) cites a report of a conference of acclimatization societies held that year in which reference is made to the "ravages of natural enemies—shags, gulls, eels, &c."

It is certain that trout must now be more numerous in relation to their natural enemies than when first introduced. The extent and effects of changes in relationship since that time are much less clear. Only three predators are known to be sufficiently widely spread or generally abundant to merit consideration here. These are the bully (*G. gobioides*), the black shag or cormorant (*P. carbo*), and the long-finned eel (*A. dieffenbachii*). The bully, which commonly does not exceed 8·5 cm. in length, is known to eat trout fry. Bullies themselves, however, are eaten sometimes extensively particularly by trout of large size but larval specimens have been found by the writer in the stomachs of trout fry. The little that is known of the interrelationships of trout and bullies suggests it as likely that bullies are preyed upon more than trout. Shags, which quite commonly feed largely on trout, feed also in the sea. Inland they are now hunted so extensively by man, in the belief that they are inimical to trout fisheries, as to suggest it as unlikely that they now attack as large a proportion of the components of most populations of trout as they did shortly after trout became established. With eels, which are extremely abundant and reach large sizes in most waters, the position may be otherwise. Eels and trout to a considerable extent utilize the same food resources. Trout are available to eels as food from the time the former emerge from the spawning-redds and are to some extent preyed upon by eels in most waters. Eels in New Zealand, except during brief periods of migration, live buried under cover in the beds of streams until they attain a length of 12 in. or 14 in. They are rarely found in the stomachs of trout and were wholly absent from those recorded earlier. The facts suggest that the balance of predatism strongly favours the eel. While the eel is one (and possibly a major one) of the factors which cause losses of trout, it is not known whether it contributes to the regulation of the densities of trout populations by varying its influence in accordance with changes of such densities.

Of the three natural enemies discussed, the eel appears most likely, under existing conditions, to exercise some controlling influence on the density of stocks of trout. No case was found where eels regulated the numbers of a population of trout and so stopped it developing to a stage where it would have destroyed eggs by superimposing redds. Therefore, commonly eels may at the most only contribute to the regulation of densities of trout populations.

4. EXPLOITABLE EXCESSES OF NATURAL POPULATIONS.

There is no question more vitally important in fisheries science than that of the optimum level at which a stock should be kept in order to permit of the maximum economic exploitation. In essence, it is a question of distinguishing between capital and interest. The difficulty of making the distinction arises from the fact that here for a time, but a limited time only, interest is added to capital and, as such, becomes productive of more interest. Later, however, a stage is reached where, for a time, interest at a declining rate accumulates to form progressively less productive capital until, finally, the capital earns only sufficient to provide for the maintenance of the fund. The fact that marine stocks have usually been depleted before the aid of biologists has been sought has made difficult the estimation of exploitable excesses. Hjort and co-workers (1933) have displayed considerable ingenuity in estimating the optimum density of a population of whales from the statistical records of declining catches. Thompson (1936), in the case of

halibut, has proceeded towards the same end by studying the effects on the growth-death ratio of experimental modifications of the degree of exploitation. In neither case, however, was it necessary to consider the question of the mode of regulation of populations in pre-depletion times. Where circumstances permit of its employment, the latter form of approach has much to commend it. Here, consideration will be limited to hypothetical natural populations of trout, some of the spawning-redds of which are superimposed with resultant loss. For convenience, and without sacrifice of principle, such populations will be considered as fixed in size and not subject to the fluctuations which do in fact occur.

A population of trout at a state of balance produces a like number of eggs to that from which its components developed. Thus it may be regarded as the product of eggs to the same number as it itself produces. The eggs fall into these categories: (*a*) the very few required for stock replacement purposes, (*b*) the many which satisfy the demands of the various lethal factors before there can be any replacement, (*c*) the balance which the population itself destroys through superimposition. The regular destruction by a population of a proportion of its own eggs is a demonstration, (1) of an ability to exist on a lower egg-production, and (2) of the inability of environmental influences otherwise to condition sufficiently the fecundity of a stock to the capacity of that environment.

Destruction of eggs by a population shows the existence of an excess of eggs capable of being exploited. Where there is uneconomic production of eggs, there is an exploitable excess of mature fish. Because superimposition, as a lethal factor, limits its destruction to excesses, the extent of its operation must be inverse to the combined effect of all other lethal factors. Therefore the extent of superimposition affords (1) a measure of the degree of frustration of an urge to increase, and (2) an index to the extent of the exploitable excess.

How is the extent of the biologically uneconomic and therefore exploitable portion of a stock to be determined? A stock of trout is the product of a production of eggs equivalent to its own. More particularly, it results from a production equivalent to its own, but less the number of eggs destroyed through superimposition. Equally is this so of the average pair of fish, which may be regarded as a similar result to that of its own efficient spawning—*i.e.*, actual production, less losses through superimposition. Spawners are divisible into three groups: (*a*) Those which lodge eggs without destroying others; (*b*) those which lodge their eggs and which, while destroying others, still add to the total eggs already in the redds; and (*c*) (if superimposition becomes intensive enough) those which, in lodging their eggs, destroy as many as they lodge. It is clear that any fish of the third type comprise a non-productive part of the population and, as such, are an exploitable excess. To them must be added such fish in the second group as spawn efficiently too few eggs to replace the producers. A stock is at its optimum density when it comprises the maximum number of pairs each of which can efficiently spawn at least sufficient eggs to effect its own replacement. The exploitable portion of the stock will comprise any excess of individuals over this quantity, for these will add to the spawning-areas less eggs than are needed to effect their replacement. An illustration will make this clearer. Suppose a population consists of one hundred pairs of mature fish. Each female produces one thousand eggs. Of these fish, sixty spawn before superimposition commences. Thereafter each successive spawner destroys fifty more eggs

than did the fish which spawned immediately before it, until a stage is reached where the last spawners simply replace the eggs they destroy in burying their own. Thus :—

Females Nos. 1 to 60 produce 60,000 eggs, waste 0, and efficiently lodge 60,000.

Females Nos. 61 to 66 produce 6,000 eggs, waste 1,050, and efficiently lodge 4,950.

Females Nos. 67 to 80 produce 14,000 eggs, waste 9,450, and efficiently lodge 4,550.

Females Nos. 81 to 100 produce 20,000 eggs, waste 20,000, and efficiently lodge 0.

Totals : Production = 100,000 ; waste = 30,500 ; efficient lodgment = 69,500.

The efficient lodgment of the average female is 695 eggs and the average wastage is 305. The sixty-sixth spawner efficiently deposits 700 eggs ; the sixty-seventh, only 650—too few to effect its own replacement. Therefore, as 695 ova are required to produce a pair of fish, producers of less than that number comprise an exploitable excess. Thus the exploitable portion of the population comprises 34 pairs of mature fish. If these are removed, the remaining 66 will have an efficient deposition of 64,950 eggs, a number sufficient to produce $\frac{64,950}{695}$ pairs—*i.e.*, approximately 93. Thus in succeeding years, a crop of 93 — 66 = 27 pairs will be available. If, in the present instance, exploitation level were fixed at any lower point, this would be done at the expense of brood fish capable of producing an exploitable excess. Conversely, the taking of smaller crops would result in the maintenance of mature but useless fish.

It is to be expected that in practice conditions might in some respects be other than as shown as this hypothetical case. For instance, numerical equality of sexes has been assumed, although it was found earlier—Hobbs (1937)—that fertilization of ova was normally efficient where females greatly outnumbered males. Therefore heavier exploitation of males than of females might be possible where sexes occur in more even numbers. Again natural fluctuations have been ignored : an even production of eggs by different fish and a regular rate of increase of superimposition losses have been assumed : secondary effects of exploitation—possible where other factors contribute to the control of density—have been discounted. The validity of the principle involved is not affected by such points which, at the most, affect the difficulty of its application.

5. POPULATIONS UNDER CONTROL.

It is clear from the foregoing that estimations in the manner described of the extent of exploitable excesses are possible only where stocks are permitted to develop to their full extent. An exploited stock or an artificially maintained one presents an unsuitable subject for such estimations. The weight of evidence is such as to suggest that usually in New Zealand stocks develop until superimposition losses are occurring. It is clear that, where this is so, the optimum level at which to hold a stock to ensure its maximum continued yield is at some point after superimposition has commenced but before it reaches a stage where further spawners destroy a like number of eggs to those they themselves produce. Protection of a

stock from exploitation is necessary to this point, but not beyond it. The intelligent management of trout fisheries demands that a natural stock be given just such a measure of protection that the maximum number of brood fish are permitted to make efficient use of the spawning-facilities. If cases should be found where factors other than those arising from limitations of spawning-ground regulate density, then optimum density would be at such point, short of the maximum, as gave the greatest continuing yield.

It is an essential characteristic of a natural population that it should tend always to maintain pressure against influences regulating its density and that, for this purpose, it should possess a reserve of regenerative power which will come automatically into use when, for any reason, the density falls. The occurrence of fluctuations in conditions affecting densities renders it necessary that populations should have this recuperative capacity. When man exploits intelligently, he does so by taking advantage of the capacity of a population to build up again to its former density. Fish introduced into new environments, as was the case in New Zealand, must either have increased and produced natural populations possessing exploitable surpluses or they must have perished.

In contrast with natural populations are stocks maintained wholly by man's periodical releases. The general question of optimum density of such stocks need not be discussed here, except that it may be remarked that, in so far as it involves a consideration of food resources, the same principle applies—that is to say, it is a question of utilization of exploitable excesses of populations of food animals.

Most New Zealand angling waters fall between the two extremes, in that their populations regularly receive contributions from natural sources and less regularly from artificial transfers. In such cases it is clear that—

(1) If there is present an accumulated excess of fish for which spawning-grounds are not available, exploitation may be possible for a while without there being any consequent reduction in the birth-rate.

(2) Even after any such excess has been removed, a further number of brood fish may be taken without the number of births falling in proportion to the fall in the number of adults.

(3) When a stock has been reduced to its optimum level and is making the most efficient use of spawning-areas (and, indeed, at any lower level, for the efficiency of spawning of the average fish would then be still higher), it is capable of producing at regular intervals an excess of mature fish over the number required to maintain the stock at that level.

(4) It is uneconomic to keep a stock below the level at which it reproduces most efficiently, for where this is done less fish may be taken regularly than could be produced for exploitation.

(5) Further, it is uneconomic to keep a stock below this level and to make liberations regularly. This necessitates the expenditure of money in effecting what the stock itself would effect if exploitation were intelligently managed.

(6) If a stock is maintained at the optimum level, no advantage accrues from the liberation of fish to provide quantities in excess of the number it is desired to abstract.

(7) Liberations of fish even just sufficient to balance abstractions may not serve a wholly useful purpose if they safeguard from exploitation the quantity of fish which is produced naturally.

(8) Certain difficulties are encountered if, in order to provide additional fishing, attempts are made to maintain a stock by liberations at a level above that which can be provided by natural reproduction. Trout initially liberated into suitable environments and those released subsequently before populations develop to their optimum densities are capable of increasing the efficient breeding-stock. Trout added once this level is passed will not produce an exploitable excess by reproduction and will indeed be incapable of effecting the replacement of such of their number as escape exploitation. Thus the indirect effects of liberations on densities of populations will be different at different densities. Because of this, attempts to maintain the same standard of fishing for an increased number of anglers will fail if liberations are increased only in proportion to the increase in number of anglers. Natural reproduction would make no corresponding increase. To provide for additional anglers, liberations would need to be increased disproportionately.

Because the principles involved in it are the same as some of those considered here, reference is made to a study of liberations of pheasants in relation to numbers killed in the State of Connecticut (Connecticut State Brd. of Fisheries and Game, 1936). This study showed that the success of shooting seasons is dependent mostly on the results of natural reproduction and that the liberations of pheasants contribute to the success of subsequent shooting seasons only indirectly by providing breeding-stock. Increase of liberations was most effective so long as the environment was capable of providing additional birds with similarly good opportunities of thriving and breeding. The failure of the pheasant stock to continue to develop proportionately to the increase in liberations suggests that, when the stock passed a certain level, either the efficiency of reproduction fell or the natural mortality-rate increased, with the result that additional excesses in proportion to liberations did not become available for exploitation.

The question of man's endeavours to aid the maintenance of stock will be considered further in a subsequent paper. It is sufficient meanwhile to note that very generally in New Zealand it is assumed that liberations of trout are necessary to maintain stocks in most waters and that to a considerable extent consideration is limited to the questions of what quantities of fish can be liberated and at what size they are best liberated. It is assumed that liberations constitute the best form of investment and accomplish a useful purpose, and little consideration is given to the following matters :—

(1) The extent of the increase, if any, in the percentage hatched when eggs are incubated under artificial conditions.

(2) The relative extents of contributions made to different stocks from natural and from hatchery sources.

(3) The relative results obtained from like sums of money invested in hatchery-work or in other directions—*e.g.*, protection from illegal fishing, predator control, artificial extension of spawning-areas, or improvement of food resources.

(4) The possibilities of game fishes other than trout being able to make more efficient use of an environment than trout can, and of them being able to produce satisfactory exploitable excesses where trout stocks could only be maintained by liberations.

Where increase of a natural population is desired, then in principle at least it should be effected by relieving the pressure of the factor governing density and not by taking steps which add to the intensity of its operation. Ruhl (1936), in a report on the stock of deer herds in Michigan, finds that where they are allowed to increase greatly, competition for food results in heavy losses by starvation, especially of the youngest beasts, which are unable to reach vegetation at the upper limits of the "browse line." Release of further deer in such areas or attempts at increase through reduction of predators would aggravate an unsatisfactory condition, which is properly remediable by increasing food resources. Again, where increase of populations of rock-oysters has been desired, it has not been effected by repeated releases of spat in areas where competition for living-space on rocks already limits the extent of the population. Rather has it been effected by increasing the area of rock surface suitable for fixation and subsequent growth of oysters.

The wisdom may well be questioned of attempting, artificially, to aid the natural increase of populations (be they of deer, oysters, or trout) by releases into areas where a natural ability to increase is already being frustrated by competition which results from an environmental limitation and which results in the destruction by a population of part of its own product. In principle the most appropriate measure is to remove the cause of the competition. Further fish made available in this manner will alone be able to ensure their own replacement and the production of an additional exploitable excess.* Considerations of practicability and cost may sometimes render unsuitable the employment of methods most desirable in principle. That this may be so is an inadequate ground for neglecting the study and experimental employment of such methods.

The intelligent exploitation of wild populations of trout calls for a knowledge of the nature and extent of operation of factors which regulate density. Attempts at control of wild populations, with a view to permitting their further development, demand at least a careful consideration of the possibilities of overcoming deficiencies which induce competition and thereby cause populations to regulate their densities. Control of populations so useful to man as trout are is equally as desirable as is control of noxious ones. Nicholson's dicta (1937), which follow, are used in a discussion of control largely of insect pests, but are cited here as equally applicable to control of the populations which form the subject of this study. He states, "If we can achieve a detailed understanding of the mechanism by which the actual population densities of animals are determined, we shall greatly advance our knowledge of biology. In addition, we may well find that we have acquired greatly increased powers of regulating animal populations to our requirements."

CONCLUSIONS.

(1) Generally data now presented are consistent with those presented earlier (Hobbs, 1937). The wide application of conclusions then arrived at is shown by the results of parallel studies made in widely separated parts of New Zealand, offering the principal contrasts of conditions that the better-known angling waters of this country show—that is to say, natural reproduction of introduced brown and rainbow trout is, under favourable

* Because fish liberated from hatcheries come from eggs taken from a very few streams in New Zealand, the hatchery system relieves the pressure on spawning-grounds in these very few streams and tends to increase it in most.

conditions, a highly efficient process, and favourable conditions are the rule and unfavourable the exception in New Zealand trout streams.

(2) The development of populations of trout in New Zealand waters has been successful where satisfactory facilities for natural reproduction exist. Because, whether or not liberations are still made regularly, stocks in all streams examined have developed to a stage where available spawning-grounds are so extensively used that a proportion of redds are superimposed on earlier ones, with attendant loss, it seems reasonable to infer that the introduction of trout has been successful largely according to the extent that facilities for reproduction exist.

(3) The fact that cases have not been found of growth of populations being arrested before superimposition losses commence indicates that other factors alone are not usually competent to arrest development of populations earlier.

(4) Populations of trout in New Zealand commonly produce more eggs than are necessary to effect their own maintenance, and destroy, by superimposition of spawning-redds, the excess over what are required for maintenance purposes. It follows that, where this is so, reduction (within limits) of a population increases the efficiency of reproduction of the average component by reducing the superimposition loss. Conversely, increase of population by means other than artificial extension of spawning-areas will decrease the efficiency of spawning of the average component.

SUMMARY.

(1) Methods described earlier (Hobbs, 1937) for the study of the extent of losses in natural spawning-redds of certain species of Salmonidæ have been applied, in slightly modified form, to the natural reproduction of brown and rainbow trout in further portions of New Zealand.

(2) The present paper covers observations made in the years 1935, 1936, and 1937 in the Southland, Otago, and Auckland Provinces.

(3) Collections comprise 542 samples from natural redds, which total 429,514 specimens of ova and larval fish.

(4) Of 71,403 ova taken during the especially vulnerable pre-eyed stage of development, dead amounted to 5·29 per cent.

(5) Of 203,525 ova taken subsequently, dead pre-eyed specimens amounted to 7·10 per cent. and the dead eyed ova to 1·28 per cent.

(6) Of 154,586 specimens in more advanced samples, dead ova amounted to 8·18 per cent.; the balance of 141,935 comprised larval fish, of which 0·27 per cent. were dead.

(7) Collections were made from sixty-four streams comprising parts of ten river-systems.

(8) In nine systems from which sufficient data are available, losses of the following extents are estimated to have occurred before hatching: 3·20, 4·64, 5·50, 6·08, 6·85, 9·36, 11·38, 12·86, and 29·29 per cent. The methods of estimation of total loss from a series of samples showing losses to different points of development are methods likely to give an approximate result only. It is considered that any errors consequent on their employment are likely to be of less extent than those attributable to the exigencies of sampling.

(9) An extremely low rate of mortality between the times of hatching of eggs and emergence of fry from redds is found regularly. In only one of the nine river-systems did dead larval fish recovered exceed 1 per cent.

(10) A study of loss frequencies shows that losses are extremely low in the great majority of redds. The differences in estimated losses from one river-system to another result largely from differences in the proportions of widely aberrant cases encountered.

(11) Heavy losses in redds are associated with the presence of excessive quantities of fine silty matter. This condition not infrequently results from or is aggravated by the precipitation of matter displaced by later spawners when constructing adjacent redds.

(12) Losses already mentioned are exclusive of such as result from agencies which effect the removal of ova or alevins from redds. Two agencies are known to accomplish this: (*a*) flood action, and (*b*) later spawners.

(13) There is evidence that destruction of spawning-redds by flood action sometimes occurs. It is shown, however, that in certain streams where the prospect of flood loss is greater than in most New Zealand waters small sample series of redds were not adversely affected in either of two successive years. Generally it appears that the selection of sites and mode of burial of eggs are such as to ensure protection from normal direct flood action. Long-term observations are still needed, however, to show the frequence and extent of flood losses.

(14) It is shown (*a*) that the conditions trout require for spawning are very special; (*b*) that the extent of areas offering such conditions is very limited, even in streams with beds predominantly of gravel from the hills to the sea; (*c*) that, rather than spawn in unsatisfactory materials, later spawners occupy sites previously used by early spawners; (*d*) that losses arise through the superimposition of redds; (*e*) that very generally in New Zealand stocks have developed to the point where a considerable proportion of redds are superimposed; (*f*) the extent of losses so caused has not been measured, but it is indicated that they are fairly extensive.

(15) The essential characteristics of factors capable of regulating the density of natural populations are discussed. It is shown that superimposition possesses these characteristics and is a usual condition in New Zealand streams. The questions (*a*) of what portion of a population constitutes an exploitable excess, and (*b*) of the optimum density at which to maintain populations, are considered.

(16) Estimates based on the counting and sampling of redds in a few streams and data obtained from trapping spawning-runs in a few others gives some indications of the extent of production of ova where qualitative samples were collected.

ACKNOWLEDGMENTS.

Indebtedness is acknowledged to—

The acclimatization societies of New Zealand for providing funds for the work.

Members and staffs of the Southland, Waitaki, and Auckland Acclimatization Societies for co-operation in the field.

Professor E. Percival, of Canterbury College, Christchurch, and Mr. A. E. Hefford, of the Marine Department, Wellington, for their kindly interest and encouragement.

Mr. K. R. Allen, who kindly read and criticized the manuscript.

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APPENDICES.

APPENDIX A.

River-system: Kakanui.

Stream: KAKANUI. Length, 32 miles; length of area sampled, 20 miles.
Source: Kakanui Mountains. *Mouth:* Pacific Coast of South Island.
Locality sampled: From foothills to tidal water.
Surrounding Country: Shallow depression with bed of alluvium in pastoral downs country.
Geological Features: Greywacke mountains; schist in foothills and limestone in coastal areas.
Width of Stream: 20 ft. to 60 ft. *Width of Flood-bed:* 20 yards to 400 yards.
Number of Channels: Commonly one—less frequently several.
Freshes: Mild and infrequent. *Floods:* Heavy and rare.
Flow and Depth: Mainly rippled water less than 2½ ft. deep with occasional pools to 10 ft.
Material comprising Bed: Largely rounded greywacke of 2 in. to 10 in.
Bed: Commonly fairly stable with moderate to good diatom growth—less stable in portions with braided channels.
Banks: Sometimes stable and willow-clad and sometimes of sloping shingle.
Vegetation: Bed-rooted, rarely occurs; marginal, rarely.
Stock: Brown trout throughout year, with addition of sea-run trout to 14 lb. in winter.
Samples collected: 62 (1935, 22; 1936, 39; 1937, 1).
Months of Collection of Pre-eyed Samples: August (15), September (1).
Months of Collection of Eyed Samples: August (27), September (1).
Months of Collection of Alevin Samples: August (10), September (8).
Proportion of Redds Contiguous: 47/62.

Details of samples collected are shown in Table I. All samples came from the principal stream except No. 9, which came from the Kauroo, a minor spawning tributary.

Table I.—Kakanui System.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
1	Pre-eyed ova	0·5	195	1	..	..	0·5
2	,,	0·6	367	8	..	..	2·2
3	,,	0·6	535	9	..	..	1·7
4	,,	0·7	277	2	..	..	0·7
5	,,	0·7	73	3	..	..	4·1
6	,,	0·8	244	2	..	..	0·8
7	,,	0·9	91	..	..	..	0·0
8	,,	1·0	584	11	..	..	1·9
9	,,	1·1	348	3	..	..	0·9
10	,,	1·1	199	3	..	..	1·5
11	,,	1·2	1,513	67	..	..	4·4
12	,,	1·3	2,660	63	..	..	2·4
13	,,	1·4	2,067	17	..	..	0·8
14	,,	1·4	557	8	..	..	1·4
15	,,	1·4	206	23	..	..	11·2
16	,,	1·5	472	8	..	..	1·7
17	Eyed ova	1·5	665	19	..	..	2·9
18	,,	1·6	404	12	..	..	3·0
19	,,	1·7	174	4	..	..	2·3
20	,,	1·7	1,106	39	..	..	3·5
21	,,	1·8	105	2	..	..	1·9
22	,,	1·8	293	4	..	..	1·4
23	,,	1·8	355	1	..	..	0·3

TABLE I—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
24	Eyed ova	1·8	971	7	..	..	0·7
25	,,	1·8	1,075	21	..	..	2·0
26	,,	1·9	251	3	..	..	1·2
27	,,	1·9	489	13	..	..	2·7
28	,,	2·0	1,615	26	..	..	1·6
29	,,	2·0	204	4	..	..	2·0
30	,,	2·1	745	96	1	..	13·0
31	,,	2·1	687	24	..	..	3·5
32	,,	2·2	311	3	..	..	1·0
33	,,	2·2	181	26	10	..	19·9
34	,,	2·3	1,302	40	..	..	3·1
35	,,	2·3	50	4	1	..	10·0
36	,,	2·3	659	13	..	..	2·0
37	,,	2·4	218	11	..	..	5·0
38	,,	2·4	238	1	..	..	0·4
39	,,	2·5	114	..	..	..	0·0
40	,,	2·6	921	11	..	..	1·2
41	,,	2·6	1,145	17	..	..	1·5
42	,,	2·6	1,708	46	5	..	3·0
43	,,	2·6	1,300	83	2	..	6·5
44	,,	2·7	191	2	..	..	1·0
		Per Cent.					
45	Alevins	31	1,698	30	..	..	1·8
46	,,	34	1,198	23	13	..	3·0
47	,,	34	748	36	..	..	4·8
48	,,	39	2,024	44	1	..	2·2
49	,,	45	854	21	2	4	3·2
50	,,	47	352	3	..	..	0·9
51	,,	51	72	2	..	..	2·8
52	,,	61	3,106	47	21	..	2·2
53	,,	63	894	8	..	2	1·1
54	,,	65	139	7	1	1	6·5
55	,,	78	622	25	..	4	4·7
56	,,	81	107	1	..	1	1·9
57	,,	83	2,509	63	..	1	2·6
58	,,	85	409	17	..	8	6·1
59	,,	88	627	124	15	1	22·3
60	,,	89	711	3	..	2	0·7
61	,,	93	778	5	..	4	1·2
62	,,	96	535	12	..	2	2·6

APPENDIX B.

RIVER-SYSTEM: WAIAU.

A.

Stream: WAIAU. Length, 77 miles; length of area sampled, 4 miles.
Source: Lake Te Anau. *Mouth:* Foveaux Strait.
Localities sampled: (*a*) Between Te Anau and Manapouri; (*b*) vicinity of Lillburn mouth; (*c*) vicinity of Orawia mouth; (*d*) entrance to tidal lagoon.
Surrounding Country: Narrow valley with bush-clad ranges broadening somewhat as alluvial flats are encountered in the lower half.
Geological Features: Moranic debris at top, with limestone and softer sedimentary rocks lower.
Width of Stream: 60 ft. to 200 ft. *Width of Flood-bed:* Rarely any, but occasionally to 400 yards.

Number of Channels : One, except where flood-bed occurs and in delta above tidal lagoon.
Freshes : Mild and infrequent. *Floods :* Mild and very rare.
Flow and Depth : Swift and occasionally turbulent water usually over 4 ft. deep with much over 6 ft.
Material comprising Bed : Predominantly rounded quartzite, much to 10 in., with increasing admixture of greywacke towards mouth.
Bed : Mainly stable with moderate to good diatom covering.
Banks : High and steep with vegetation, but less stable banks of alluvium towards mouth.
Vegetation : Bed-rooted, nil ; marginal, nil.
Stock : Mainly large brown trout, with increasing proportion of rainbow trout and Atlantic salmon near Te Anau.
Samples collected : 10 (1935, 5 ; 1937, 5).
Months of Collection of Pre-eyed Samples : July (1), August (2).
Months of Collection of Eyed Samples : August (2), September (2).
Month of Collection of Alevin Samples : September (3).
Proportion of Redds contiguous : 7/10 (but a few fish still spawning).
Extent of Spawning-areas : Very great, especially between Lakes Te Anau and Manapouri.

B.

Stream : EGLINTON. Length, 29 miles ; length of area sampled, 6 miles.
Source : Lakes Gunn and Fergus. *Mouth :* Lake Te Anau.
Localities sampled : Vicinity of 23, 24, 31, 38, 40, 43, and 44 mile pegs on Eglinton Valley Road.
Surrounding Country : Grassed flat of coarse alluvium 150 yards to 600 yards wide between steep bush-clad ranges to 6,000 ft.
Geological Features : Greywacke rock.
Width of Stream : 25 ft. to 200 ft. *Width of Flood-bed :* Nil to slight over much of course, but sometimes to 200 yards.
Number of Channels : Usually one ; rarely several.
Freshes : Moderate and frequent in autumn and spring. *Floods :* Usual with spring thaw.
Flow and Depth : Mainly rippled water less than 3 ft. deep with occasional pools to 14 ft.
Material comprising Bed : Rounded greywacke of 2 in. to 12 in. higher and to 6 in. lower down.
Bed : Very stable in upper portions where flow is lake-controlled, but decreasing lower as tributaries enter.
Banks : Commonly low—2 ft. to 4 ft. and a little eroded.
Vegetation : Bed-rooted, nil ; marginal, nil.
Stock : Predominantly brown trout to yearling size and large mature fish—intermediate-year classes absent. Very large run of spawning lake fish. Rainbow trout and Atlantic salmon also present.
Samples collected : 1937, 14.
Month of Collection of Pre-eyed Samples : October (2).
Months of Collection of Eyed Samples : September (2), October (5).
Month of Collection of Alevin Samples : October (5).
Proportion of Redds contiguous : 11/14 (but a few fish still spawning).
Extent of Spawning-areas : Possibly as great as in any water of similar size in New Zealand.

C.

Stream : UPUKERORA. Length, 25 miles ; length of area sampled, 5 miles.
Source : Livingstone Mountains. *Mouth :* Lake Te Anau.
Localities sampled : Lowest mile and fifth mile from lake.
Surrounding Country (lower 5 miles only) : Through a broadening valley floor of coarse tussock-clad alluvium in low tussock-clad hills.
Geological Features : Greywacke bed-rock at head with " papa " (soft Pliocene and Miocene rocks) lower.
Width of Stream : 20 ft. to 60 ft. *Width of Flood-bed :* Stream often confined, but in parts has flood-bed to 120 yards.
Number of Channels : Usually one, but braided in flood-bed sections.
Freshes : Moderate and frequent in autumn and spring. *Floods :* Usual with spring thaw.
Flow and Depth : Commonly rippled water up to 2 ft. deep with infrequent pools.
Material comprising Bed : Rounded greywacke of 2 in. to 12 in. Often boulders of 6 in. to 12 in. with coarse grit and lack of intermediate-sized material.

Bed : Offers extremes of stability, but commonly supports only limited diatom covering.
Banks : Commonly low—2 ft. to 4 ft. and fairly stable, but sometimes to 10 ft. and more eroded.
Vegetation : Bed-rooted, nil; marginal, nil.
Stock : As in Eglinton.
Samples collected : 12 (1935, 2; 1937, 10).
Months of Collection of Pre-eyed Samples : August (2), September (3).
Month of Collection of Eyed Samples : October (3).
Month of Collection of Alevin Samples : October (4).
Proportion of Redds contiguous : 10/12 (but a few fish still spawning).
Extent of Spawning-areas : Considerable in lower 5 miles.

D.

Stream : MARAROA. Length, 39 miles; length of area sampled, 4 miles.
Source : Livingstone Mountains and Lake Mavora. *Mouth :* Waiau River, 55 miles from sea.
Localities sampled : 7 to 10 and 21 miles from mouth.
Surrounding Country : Broad tussock-clad depression between tussock-clad ranges.
Geological Features : Bed-rock greywacke.
Width of Stream : 35 ft. to 90 ft. *Width of Flood-bed :* Stream fairly confined, but flood-bed to 200 yards in places.
Number of Channels : Usually one, but more in flood-bed sections.
Freshes : Usual in autumn and spring. *Floods :* Modified by lake, especially in upper reaches.
Flow and Depth : Swift rippled water usually less than 3 ft., with occasional deep holes.
Material comprising Bed : Rounded greywacke to 12 in., with much from 4 in. to 10 in.
Bed : Fairly stable with poor to moderate diatom covering, but unstable sections in parts.
Banks : Very often 2 ft. to 4 ft., stable, with overhanging tussock—less commonly high eroded coarse alluvium.
Vegetation : Bed-rooted, nil; marginal, nil.
Stock : As in Eglinton, but few, if any, rainbow or salmon.
Samples collected : 1937, 5.
Month of Collection of Alevin Samples : October (5).
Proportion of Redds contiguous : 2/5.
Extent of Spawning-areas : Moderate where inspected, but known to be very extensive higher up.

E.

Stream : WAIRAKI. Length, 26 miles; length of area sampled, 5 miles.
Source : Takitimo Mountains. *Mouth :* Twenty-four miles up Waiau River.
Localities sampled : Lowest mile and vicinity of 7, 8, and 16 miles from mouth.
Surrounding Country : (*a*) At top, in narrow valley between steep tussock-clad slopes; (*b*) lower areas, in broad tussock-clad depression.
Geological Features : Greywacke bed-rock, with softer sedimentary rocks in lower reaches.
Width of Stream : 30 ft. to 90 ft. *Width of Flood-bed :* Stream mainly confined, but with flood-bed to 350 yards generally in lower few miles.
Number of Channels : Usually one, but dividing in flood-bed portions.
Freshes : Mainly autumn and spring. *Floods :* Usual with spring thaw.
Flow and Depth : Swift rippled water usually less than 3 ft., with infrequent deeper holes.
Material comprising Bed : Rounded greywacke usually from 2 in. to 12 in.
Bed : Unstable in lowest area, and stable with moderate diatom growth in two upper areas.
Banks : Generally from 2 ft. to 5 ft. and fairly stable. Lateral erosion most active in lowest 3 miles.
Vegetation : Bed-rooted, nil; marginal, nil.
Stock : As in Eglinton, but few, if any, salmon and rainbow.
Samples collected : 1937, 9.
Month of Collection : Five eyed and 4 alevin samples in October.
Proportion of Redds contiguous : 4/9.
Extent of Spawning-areas : Bottom section, very limited; mid-section, limited; top section, extensive.

F.

Sub-system : ORAWIA (Orauea). Observations were made in the Orawia River up to its junction with the Ohai and thence up the principal spawning branch, the Ohai and its tributaries—Morley and Coal Creeks.

Source : Low hills connecting Takitimo Mountains and Longwood Range. *Mouth :* Waiau River, 8 miles above sea.

Localities sampled : Orawia, vicinity of Orawia Township; Ohai, at Birchwood and Ohai Townships; Morley, lower 2 miles; Coal Creek, lowest mile.

Surrounding Country : Low tussock-clad hills and downs.

Geological Features : Upper portion of watershed, bed-rock is hard sedimentary and, lower down, soft sedimentary.

Width of Stream : Orawia, 20 ft. to 50 ft.; Ohai, 8 ft. to 20 ft.; Morley, 6 ft. to 15 ft.; Coal Creek, 3 ft. to 5 ft. In portions of the principal stream there is a flood-bed, but not in the tributaries.

Number of Channels : One in each of minor streams, and usually one in major stream.

Freshes : Irregular throughout year. *Floods :* Occasional.

Flow and Depth : The gradients of these streams are less than of other Waiau waters—the flow is more frequently broken by pools. Much under 2 ft. deep in tributaries and under 3½ ft. in Orawia.

Material comprising Beds : Gravel of a variety of sizes, with finer deposits.

Beds : Stable to very stable, with moderate to rich diatom covering in spawning-areas.

Banks : 1 ft. to 4 ft. high and generally stable with covering vegetation.

Vegetation : Bed-rooted, limited quantity in each stream; marginal, nil.

Stock : Brown trout 1 lb. to 2 lb., with addition of large trout in spawning season.

Samples collected : 32 (1935, 7; 1936, 8; 1937, 17).

Months of Collection of Pre-eyed Samples : July (2), August (4).

Months of Collection of Eyed Samples : August (1), September (8), October (3).

Months of Collection of Alevin Samples : September (2), October (12).

Proportion of Redds contiguous : 28/32 (but a few fish still spawning).

Extent of Spawning-areas : Limited in Orawia, but extensive in Ohai and Morley.

TABLE II.

Waiau River	Waiau system,	Series A.
Eglinton River	,,	Series B.
Upukerora River	,,	Series C.
Mararoa River	,,	Series D.
Wairaki River	,,	Series E.
Orawia sub-system	,,	Series F.
Sundry minor tributaries	,,	Series G.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series A.				
1	Pre-eyed ova ..	0·7	158	2	..	..	1·3
2 ..	,, ..	0·8	284	2	..	..	0·7
3 ..	,, ..	1·0	683	14	..	..	2·0
4 ..	Eyed ova ..	1·5	588	14	1	..	2·6
5 ..	,, ..	1·9	291	2	..	..	0·7
6 ..	,, ..	1·9	394	4	..	..	1·0
7 ..	,, ..	2·0	569	8	1	..	1·6
		Per Cent.					
8 ..	Alevins ..	43	313	19	2	..	6·7
9 ..	,, ..	80	278	56	108	1	59·4
10 ..	,, ..	93	280	11	5	2	6·4

TABLE II—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series B.				
11 ..	Pre-eyed ova ..	1·1	1,199	128	..	..	10·7
12 ..	,, ..	1·2	1,375	92	..	..	6·7
13 ..	Eyed ova ..	1·5	206	14	3	..	8·3
14 ..	,, ..	1·6	3,824	443	93	..	14·0
15 ..	,, ..	1·9	2,604	70	6	..	2·9
16 ..	,, ..	2·2	1,235	42	2	..	3·6
17 ..	,, ..	2·4	2,281	260	312	..	25·1
18 ..	,, ..	2·4	1,405	51	2	..	3·8
19 ..	,, ..	2·4	1,915	368	..	..	19·2
		Per Cent.					
20 ..	Alevins ..	50	1,705	252	94	13	21·1
21 ..	,, ..	60	226	101	..	..	44·7
22 ..	,, ..	79	2,654	104	..	1	4·0
23 ..	,, ..	87	389	89	21	..	28·3
24 ..	,, ..	95	2,254	68	..	1	3·1
			Series C.				
25 ..	Pre-eyed ova ..	0·9	589	3	..	..	0·5
26 ..	,, ..	1·1	792	20	..	..	2·5
27 ..	,, ..	1·2	282	6	..	..	2·1
28 ..	,, ..	1·2	1,058	71	..	..	6·7
29 ..	,, ..	1·3	1,764	107	..	..	6·1
30 ..	Eyed ova ..	1·9	1,657	778	180	..	57·8
31 ..	,, ..	2·1	2,175	29	1	..	1·4
32 ..	,, ..	2·3	3,660	1,286	169	..	39·8
		Per Cent.					
33 ..	Alevins ..	56	3,821	231	149	11	10·2
34 ..	,, ..	58	1,165	10	..	..	0·9
35 ..	,, ..	71	1,142	35	102	1	12·1
36 ..	,, ..	85	578	181	25	..	35·6
			Series D.				
		Per Cent.					
37 ..	Alevins ..	41	2,446	801	77	15	36·5
38 ..	,, ..	49	1,191	55	3	1	5·0
39 ..	,, ..	52	2,554	69	14	6	3·5
40 ..	,, ..	63	2,244	133	13	2	6·6
41 ..	,, ..	89	2,203	10	..	1	0·5
			Series E.				
42 ..	Eyed ova ..	1·7	2,543	209	3	..	8·3
43 ..	,, ..	2·2	1,405	76	3	..	5·6
44 ..	,, ..	2·3	855	69	..	..	8·1
45 ..	,, ..	2·4	2,875	25	1	..	0·9
46 ..	,, ..	2·5	458	215	48	..	57·4
		Per Cent.					
47 ..	Alevins ..	43	966	29	5	3	3·8
48 ..	,, ..	43	3,048	153	38	15	6·8
49 ..	,, ..	66	1,115	164	..	..	14·7
50 ..	,, ..	92	1,506	123	150	..	18·1

TABLE II—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series F.				
51M ..	Pre-eyed ova ..	0·7	389	7	..	..	1·8
52M ..	,, ..	0·9	479	5	..	..	1·0
53M ..	,, ..	1·1	297	4	..	..	1·3
54M ..	,, ..	1·2	290	3	..	..	1·0
55M ..	,, ..	1·3	2,601	73	..	..	2·8
56M ..	,, ..	1·4	287	4	..	..	1·4
57M ..	Eyed ova ..	1·4	297	..	..	..	0·0
58C ..	,, ..	1·5	2,315	193	..	..	8·3
59M ..	, ..	1·5	413	4	..	..	1·0
60M ..	,, ..	1·6	187	4	..	..	2·1
61M ..	,, ..	1·7	125	4	..	..	3·2
62C ..	,, ..	2·0	348	7	..	..	2·0
63C ..	,, ..	2·0	1,569	28	3	..	2·0
64C ..	,, ..	2·1	2,098	32	..	..	1·5
65M ..	,, ..	2·2	176	5	..	..	2·8
66M ..	,, ..	2·3	4,384	159	13	..	3·9
67M ..	,, ..	2·4	771	49	76	..	16·2
68M ..	,, ..	2·5	2,888	90	8	..	3·4
		Per Cent.					
69M ..	Alevins ..	26	353	24	2	..	7·4
70M ..	,, ..	36	1,463	9	..	..	0·6
71O ..	,, ..	38	913	231	13	1	26·8
72M ..	,, ..	43	1,638	15	7	..	1·3
73M ..	,, ..	55	1,080	26	3	1	2·8
74M ..	,, ..	57	716	67	..	1	9·5
75C ..	,, ..	59	1,105	187	5	..	17·4
76M ..	,, ..	59	132	6	..	..	4·5
77M ..	,, ..	59	831	202	2	..	24·5
78M ..	,, ..	60	135	7	1	..	5·9
79C ..	,, ..	62	369	85	77	2	44·4
80O ..	,, ..	73	79	3	..	..	3·8
81M ..	,, ..	74	268	42	..	..	15·7
82M ..	,, ..	86	1,133	7	3	..	0·9
			Series G.				
83R ..	Pre-eyed ova ..	1·1	1,623	116	..	..	7·1
84R ..	,, ..	1·2	1,063	291	..	..	27·4
85HB ..	Eyed ova ..	1·6	171	4	..	..	2·3
86HB ..	,, ..	1·9	2,913	249	136	..	13·2
87HB ..	,, ..	2·1	592	35	1	..	6·1
88HB ..	,, ..	2·2	1,485	163	7	..	11·4
89HC ..	,, ..	2·3	3,118	337	40	..	12·1
90HB ..	,, ..	2·4	118	6	..	..	5·1
91M ..	,, ..	2·6	1,800	51	..	..	4·1

APPENDIX C.

River-system: Aparima.

Stream: APARIMA. Length of stream, 80 miles; length of area sampled, 20 miles.
Localities sampled: Vicinity of Ringway, and from vicinity of Wrey's Bush Bridge to bridge on Mossburn Road.
Surrounding Country: After emerging from hills, the course is through a narrow tussock-clad flood-plain of coarse alluvium.
Geological Features: Greywacke bed-rock at headwaters.
Width of Stream: 30 ft. to 150 ft. *Width of Flood-bed:* 100 yards to 700 yards.
Number of Channels: Braided for from one-third to one-half its length.
Freshes: Especially in spring. *Floods:* Mainly with spring thaw.
Flow and Depth: Much shallow rippled water less than 2½ ft.; occasional deep holes against eroding banks.
Material comprising Bed: Rounded maitai (a hard sedimentary rock) of 1½ in. to 10 in.—much of 3 in. to 8 in.
Bed: Commonly unstable, except towards margins and in off-shooting channels.
Banks: Commonly sloping shingle, also steep eroded banks of coarse alluvium; less frequently low and stable with vegetation.
Vegetation: Bed-rooted, nil; marginal, nil.
Stock: Abundant stock of brown trout mainly to 2 lb., with some addition of sea-run fish in winter.
Samples collected: 37 (1935, 1; 1936, 19; 1937, 17).
Month of Collection of Pre-eyed Samples: July (1).
Month of Collection of Eyed Samples: September (13).
Month of Collection of Alevin Samples: September (23).
Samples collected from Main Channel of Stream: 15.
Samples collected from Subsidiary Channels: 22.
Proportion of Redds contiguous: 13/37.
Extent of Spawning-areas: Moderate.

Table III.

Aparima River .. .. .. Aparima system, Series A.
Sundry tributaries .. .. .. ,, Series B.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series A.				
1 ..	Pre-eyed ova ..	1·0	905	8	..	..	0·9
2 ..	Eyed ova ..	1·7	493	13	..	..	2·6
3 ..	,, ..	1·8	761	18	..	..	2·4
4 ..	,, ..	1·9	1,217	41	..	..	3·4
5 ..	,, ..	2·0	627	26	..	..	4·1
6 ..	,, ..	2·1	1,287	40	..	..	3·1
7 ..	,, ..	2·1	330	125	..	..	37·9
8 ..	,, ..	2·2	746	460	15	..	63·7
9 ..	,, ..	2·3	1,077	142	16	..	14·7
10 ..	,, ..	2·4	1,578	55	..	..	3·5
11 ..	,, ..	2·4	1,274	53	6	..	4·6
12 ..	,, ..	2·5	625	43	..	..	6·9
13 ..	,, ..	2·6	853	31	..	..	3·6
14 ..	,, ..	2·7	782	41	1	..	5·4
		Per Cent.					
15 ..	Alevins ..	38	1,179	11	1	1	1·1
16 ..	,, ..	41	541	220	8	..	42·1
17 ..	,, ..	42	1,172	16	4	..	1·7
18 ..	,, ..	48	730	22	10	1	4·5
19 ..	,, ..	54	1,142	24	13	2	3·4
20 ..	,, ..	55	750	14	..	..	1·9
21 ..	,, ..	56	836	274	1	1	33·0

TABLE III—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series A—continued.				
		Per Cent.					
22 ..	Alevins ..	61	1,620	15	1	2	1·1
23 ..	,, ..	65	287	15	26	..	14·3
24 ..	,, ..	69	979	21	7	..	2·9
25 ..	,, ..	69	2,106	52	21	3	3·6
26 ..	,, ..	73	805	5	..	1	0·7
27 ..	,, ..	77	528	151	..	2	29·0
28 ..	,, ..	79	823	17	..	1	2·2
29 ..	,, ..	82	2,465	21	..	..	0·9
30 ..	,, ..	84	884	2	2	..	0·5
31 ..	,, ..	84	84	..	..	..	0·0
32 ..	,, ..	87	1,852	15	..	..	0·8
33 ..	,, ..	87	963	15	..	..	1·6
34 ..	,, ..	89	790	98	..	23	15·3
35 ..	,, ..	90	226	..	..	3	1·3
36 ..	,, ..	95	185	..	..	..	0·0
37 ..	,, ..	100	518	1	..	..	0·2
			Series B.				
38P ..	Pre-eyed ova ..	0·9	100	2	..	..	2·0
39O ..	,, ..	1·0	241	1	..	..	0·4
40E ..	,, ..	1·2	359	..	..	..	0·0
41H ..	,, ..	1·2	263	4	..	..	1·5
42P ..	,, ..	1·3	75	2	..	..	2·7
		Per Cent.					
43H ..	Alevins ..	52	305	7	..	1	2·6

APPENDIX D.

RIVER-SYSTEM: ORETI.

Stream: ORETI. Length, 124 miles; length of area sampled, 26 miles.
Source: Thomson Mountains. *Mouth:* Foveaux Strait.
Localities sampled: 4 miles above Mossburn, Five Rivers Plain to Dipton Creek, and vicinity Centre Bush Bridge.
Surrounding Country: Flood-plain of coarse alluvium, improving to fine alluvium.
Geological Features: Bed-rock predominantly greywacke.
Width of Stream: 50 ft. to 200 ft. *Width of Flood-bed:* 100 yards to 800 yards.
Number of Channels: Usually several.
Freshes: Very frequent in October, November, December, and in late autumn. *Floods:* Usual with spring thaw, but not limited to then.
Flow and Depth: Rather fast rippled water commonly under 3 ft. deep, with frequent rippled pools to 6 ft.
Material comprising Bed: Rounded greywacke to 10 in., with much to 4 in.
Bed: Much unstable—aggrading causes frequent changes of channels in parts; most stable in older channels fed by percolating waters.
Banks: Commonly sloping shingle—in parts of coarse eroding alluvium or willow-fringed.
Vegetation: Bed-rooted, rarely occurs; marginal, nil.
Stock: Brown trout of varying sizes, with addition of large sea-run fish in winter.
Samples collected: 32 (1935, 3; 1937, 29).
Months of Collection of Pre-eyed Samples: August (2), September (1).
Months of Collection of Eyed Samples: August (8), September (6).
Months of Collection of Alevin Samples: August (4), September (11).
Samples collected from Main Channel: 5.
Samples collected from Subsidiary Channels: 27.
Proportion of Redds contiguous: 21/32.
Extent of Spawning-areas: Considerable between Dipton and Lumsden, elsewhere moderate to poor.

TABLE IV.

Oreti River .. .. Oreti system, Series A.
Sundry Oreti tributaries .. .. ,, Series B.
Spring Creek, opposite Lumsden .. .. ,, Series C.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series A.				
1 ..	Pre-eyed ova ..	1·1	84	..	..	..	3·6
2 ..	,, ..	1·1	369	..	..	..	0·0
3 ..	,, ..	1·3	427	41	..	..	9·6
4 ..	Eyed ova ..	1·5	1,080	38	12	..	4·6
5 ..	,, ..	1·5	353	3	..	..	0·8
6 ..	,, ..	1·7	113	5	..	..	4·4
7 ..	,, ..	1·9	1,231	246	..	..	20·0
8 ..	,, ..	2·0	99	4	..	..	4·0
9 ..	,, ..	2·1	598	11	..	..	1·8
10 ..	,, ..	2·2	325	15	..	..	4·6
11 ..	,, ..	2·4	2,130	83	92	..	8·2
12 ..	,, ..	2·4	97	2	1	..	3·1
13 ..	,, ..	2·5	1,044	19	..	..	1·8
14 ..	,, ..	2·5	262	9	..	..	3·4
15 ..	,, ..	2·5	1,659	14	..	..	0·8
16 ..	,, ..	2·6	177	24	..	..	13·5
17 ..	,, ..	2·6	2,142	12	3	..	0·7
		Per Cent.					
18 ..	Alevins ..	29	644	25	1	..	4·0
19 ..	,, ..	30	1,303	16	..	..	1·2
20 ..	,, ..	41	804	10	..	..	1·2
21 ..	,, ..	49	159	7	..	..	4·4
22 ..	,, ..	56	233	53	28	6	37·4
23 ..	,, ..	59	904	14	1	..	1·7
24 ..	,, ..	65	1,894	21	..	..	1·1
25 ..	,, ..	67	1,461	115	59	1	12·0
26 ..	,, ..	71	90	8	..	..	8·9
27 ..	,, ..	73	900	12	1	1	1·6
28 ..	,, ..	75	2,051	21	..	..	1·0
29 ..	,, ..	80	1,263	41	..	..	3·2
30 ..	,, ..	90	2,662	22	1	..	0·9
31 ..	,, ..	91	666	10	6	2	2·7
32 ..	,, ..	95	312	20	10	1	9·9
			Series B.				
33CH ..	Pre-eyed ova ..	0·6	280	5	..	..	1·8
34S ..	,, ..	0·7	316	4	..	..	1·3
35S ..	,, ..	0·7	722	6	..	..	0·8
36S ..	,, ..	0·8	289	1	..	..	0·3
37M ..	,, ..	1·0	1,090	7	..	..	0·6
38S ..	,, ..	1·1	277	..	..	..	0·0
39CH ..	,, ..	1·2	769	27	..	..	3·5
40F ..	,, ..	1·3	647	11	..	..	1·7
41S ..	,, ..	1·3	393	2	..	..	0·5
42F ..	,, ..	1·4	521	3	..	..	0·6

TABLE IV—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series B—continued.				
43F ..	Eyed ova ..	1·5	262	14	..	..	5·3
44F ..	,, ..	1·6	774	6	..	..	0·8
45S ..	,, ..	1·7	409	7	..	..	1·7
46F ..	,, ..	1·8	400	24	..	..	6·0
47D ..	,, ..	1·9	581	14	29	..	7·4
48I ..	,, ..	2·1	752	37	9	..	6·1
49M ..	,, ..	2·1	520	4	3	..	1·3
50D ..	,, ..	2·2	678	54	4	..	8·6
51D ..	,, ..	2·4	541	16	..	..	3·0
52I ..	,, ..	2·6	340	2	..	..	0·6
		Per Cent.					
53I ..	Alevins ..	35	1,317	21	..	..	1·6
54D ..	,, ..	55	407	4	..	..	1·0
55M ..	,, ..	58	1,095	12	10	1	2·1
56I ..	,, ..	67	473	22	1	..	4·9
57M ..	,, ..	69	847	15	4	..	2·2
58F ..	,, ..	70	870	80	168	5	29·1
59F ..	,, ..	89	1,926	21	4	..	1·3
			Series C.				
60 ..	Pre-eyed ova ..	0·8	390	5	..	..	1·3
61 ..	,, ..	0·9	789	4	..	..	0·5
62 ..	Eyed ova ..	2·0	623	3	..	..	0·5
63 ..	,, ..	2·1	293	5	..	..	1·7
64 ..	,, ..	2·3	1,956	39	..	..	2·0
65 ..	,, ..	2·3	209	..	1	..	0·5
66 ..	,, ..	2·4	290	10	..	..	3·5
67 ..	,, ..	2·4	190	13	..	..	6·8
68 ..	,, ..	2·4	531	11	..	..	2·1
69 ..	,, ..	2·4	2,072	30	1	..	1·5
70 ..	,, ..	2·5	1,016	53	15	..	6·6
71 ..	,, ..	2·6	867	3	..	..	0·3
72 ..	,, ..	2·6	402	7	..	..	1·7
73 ..	,, ..	2·7	197	11	..	..	5·6
74 ..	,, ..	2·7	119	..	..	..	0·0
		Per Cent.					
75 ..	Alevins ..	43	327	41	..	..	12·5
76 ..	,, ..	45	640	3	..	..	0·5
77 ..	,, ..	47	1,288	54	..	..	4·2
78 ..	,, ..	50	793	24	..	..	3·0
79 ..	,, ..	94	549	1	..	..	0·2
80 ..	,, ..	96	107	..	..	..	0·0

Makarewa Sub-system.

Of the thirty-two samples from the Makarewa sub-system, three were collected in 1935, two in 1936, and twenty-seven in 1937.

Months of Collection of Pre-eyed Samples : July (3), September (1).
Month of Collection of Eyed Samples : September (13).
Month of Collection of Alevin Samples : September (15).
Proportion of Redds contiguous : 26/32.

Table V.

Makarewa sub-system .. .. .. Oreti system, Series D.
Makarewa and Hedgehope .. .. ,, Series D1.
Otapiri and Lora .. .. .. ,, Series D2.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series D1.				
81H ..	Eyed ova ..	1·8	206	3	1	..	1·9
82M ..	,, ..	2·1	332	17	..	..	5·1
83H ..	,, ..	2·1	216	10	..	..	4·6
84H ..	,, ..	2·4	569	13	3	..	2·8
85H ..	,, ..	2·4	678	38	..	..	5·6
86M ..	,, ..	2·5	609	28	10	..	6·2
		Per Cent.					
87H ..	Alevins ..	30	133	71	16	..	65·4
88M ..	,, ..	43	433	34	20	..	12·5
89M ..	,, ..	47	160	2	..	..	1·2
90H ..	,, ..	77	455	14	..	..	3·1
			Series D2.				
91O ..	Pre-eyed ova ..	0·6	298	..	..	..	0·0
92L ..	,, ..	0·7	265	1	..	..	0·4
93O ..	,, ..	0·8	81	1	..	..	1·2
94L ..	,, ..	1·0	312	11	..	..	3·5
95O ..	,, ..	1·3	157	11	..	..	7·0
96O ..	Eyed ova ..	1·5	477	13	1	..	2·9
97O ..	,, ..	1·9	770	19	59	..	10·1
98O ..	,, ..	2·0	1,189	48	12	..	5·0
99O ..	,, ..	2·2	1,358	102	22	..	9·1
100O ..	,, ..	2·3	663	17	..	..	2·6
101O ..	,, ..	2·4	667	32	..	..	4·8
102O ..	,, ..	2·5	367	2	..	..	0·5
		Per Cent.					
103O ..	Alevins ..	44	653	75	4	..	12·1
104O ..	,, ..	49	85	2	..	..	2·4
105O ..	,, ..	54	388	19	53	..	18·6
106O ..	,, ..	58	730	1	..	..	0·1
107O ..	,, ..	64	202	23	1	..	11·9
108O ..	,, ..	69	1,227	9	..	9	1·5
109O ..	,, ..	74	144	1	1	..	1·4
110O ..	,, ..	75	235	8	..	..	3·4
111O ..	,, ..	84	870	15	1	5	2·4
112O ..	,, ..	93	195	11	..	1	6·2

APPENDIX E.

River-system : Waituna.

Stream : WAITUNA CREEK. Length, 16 miles; length of area sampled, 4 miles.
Source : Plains—surface water.
Localities sampled : Lowest mile and near Mokotua.
Surrounding Country : Flat with red tussock, *Sphagnum* bog, and residual forest.
Geological Features : Bed-rock, nil; alluvial formation, clay overlying quartz gravel of Mataura origin.
Width of Stream : 5 ft. to 15 ft.—mostly in artificial channel of 10 ft.
Number of Channels : One only.
Freshes : Frequent—subsidence very slow. *Floods :* Nil.
Flow and Depth : Quiet flowing and 6 in. to 18 in. deep in channelled portion, with holes to 4½ ft. elsewhere.
Material comprising Bed : Clay, and less commonly rounded quartz gravel to 2½ in.
Bed : Very stable.
Banks : Stable clay, steep, and rising to 10 ft. in channel, elsewhere stable and tussock or flax-clad.
Vegetation : Bed-rooted, prolific growth; marginal, nil.
Stock : Brown trout—mainly 3 lb. to 9 lb. in winter, and, in summer, fry only.
Samples collected : 28 (1935, 18; 1936, 10).
Month of Collection of Pre-eyed Samples : July (3).
Months of Collection of Eyed Samples : August (6), September (4).
Months of Collection of Alevin Samples : August (2), September (6).
Proportion of Redds contiguous : 25/28.

Table VI.—Waituna Creek.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
1	Pre-eyed ova	0·9	289	19	..	..	6·6
2	,,	1·0	499	4	..	..	0·8
3	,,	1·1	278	8	..	..	2·9
4	Eyed ova	1·2	56	6	..	..	10·7
5	,,	1·5	316	5	..	..	1·6
6	,,	1·6	300	19	1	..	6·7
7	,,	1·7	1,154	386	31	..	36·1
8	,,	1·7	208	34	2	..	17·3
9	,,	1·7	855	38	..	..	4·4
10	,,	1·8	201	4	..	..	2·0
11	,,	1·9	196	43	..	..	21·9
12	,,	2·1	60	8	11	..	31·6
13	,,	2·1	751	449	34	..	64·3
14	,,	2·1	486	45	..	..	9·2
15, 16, 17	,,	2·1	2,324	627	165	..	34·0
18	,,	2·2	2,805	1,174	77	..	44·5
19	,,	2·2	625	5	..	..	0·8
20	,,	2·3	1,742	48	561	..	35·0
21	,,	2·4	306	17	108	..	40·8
22	,,	2·7	407	17	13	..	7·4
		Per Cent.					
23	Alevins	26	104	13	2	..	14·4
24, 25	,,	30	772	95	36	..	17·0
26	,,	32	260	15	21	..	13·8
27	,,	38	197	24	..	..	12·2
28	,,	91	252	36	6	1	17·0

APPENDIX F.

River-system : Mataura.

Stream : MATAURA. Length, 151 miles ; length of area sampled, 18 miles.
Source : Eyre Mountains.
Localities sampled : Vicinities of Garston, Athol, Parawa, and entrance of Nokomai Creek.
Surrounding Country : Through narrow fertile alluvial flat between ranges to Parawa, and thereafter through poor alluvium and against foot of steep range.
Geological Features : Predominantly schist bed-rock.
Number of Channels : Usually one, but sometimes braided below Parawa.
Freshes : Infrequent. *Floods :* With spring thaw, more especially from Eyre Creek down.
Flow and Depth : Mainly rippled water to 3 ft., with occasional holes to 10 ft.
Material comprising Bed : Mainly schist gravel to 2½ in. above Eyre Creek, with addition of greywacke to 10 in. below.
Bed : Fairly stable to very stable above Eyre Creek, thereafter unstable to fairly stable.
Banks : 4 ft. to 10 ft. steep and stable, often willow-clad above Eyre Creek ; thereafter in parts sloping shingle and in parts stable and grass-covered.
Vegetation : Bed-rooted, in parts for short distance above Eyre Creek only.
Stock : Brown trout—mixed sizes to 5 lb.
Samples collected : 1937, 17.
Month of Collection of Five Eyed Ova and Twelve Alevin Samples : September.
Proportion of Redds contiguous : 6/17.

Table VII.

Mataura River	Mataura system, Series A.
Whakaea sub-system	,, Series B.
Waikaka, Mairurua, or Mimihau ..	,, Series C.
Otamita	,, Series D.
Tomogalak	,, Series E.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead. per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series A.				
1 ..	Eyed ova ..	1·6	296	3	..	..	1·0
2 ..	,, ..	2·0	703	11	1	..	1·7
3 ..	,, ..	2·2	1,152	16	1	..	1·5
4 ..	,, ..	2·3	892	5	1	..	0·7
5 ..	,, ..	2·5	535	6	..	..	1·1
		Per Cent.					
6 ..	Alevins ..	39	434	103	17	2	28·1
7 ..	,, ..	45	193	99	29	..	66·3
8 ..	,, ..	45	1,780	157	47	..	11·5
9 ..	,, ..	62	365	14	..	..	3·8
10 ..	,, ..	63	1,043	56	92	3	14·5
11 ..	,, ..	68	130	1	..	..	0·8
12 ..	,, ..	76	1,120	49	16	..	5·8
13 ..	,, ..	80	538	2	..	..	0·4
14 ..	,, ..	83	721	108	2	35	20·1
15 ..	,, ..	83	1,882	51	..	..	2·7
16 ..	,, ..	86	1,061	14	..	1	1·4
17 ..	,, ..	95	804	21	..	11	4·0

TABLE VII—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series B.				
18D ..	Pre-eyed ova ..	1·3	438	15	..	..	3·4
19D ..	Eyed ova ..	1·5	81	6	2	..	9·9
20D ..	,, ..	1·8	662	47	..	..	7·1
21A ..	,, ..	2·0	287	6	..	..	2·1
22D ..	,, ..	2·1	488	16	..	..	3·3
23D ..	,, ..	2·3	1,600	30	5	..	2·2
24G ..	,, ..	2·3	1,051	13	..	..	1·2
25D ..	,, ..	2·4	621	35	..	..	5·6
26G ..	,, ..	2·5	1,737	42	17	..	3·4
27D ..	,, ..	2·5	1,294	26	1	..	2·1
28G ..	,, ..	2·6	1,824	77	2	..	4·3
		Per Cent.					
29A ..	Alevins ..	45	607	14	1	..	2·5
			Series C.				
30MI ..	Pre-eyed ova ..	0·5	472	3	..	..	0·6
31MAI ..	,, ..	0·6	356	7	..	..	2·0
32WAI ..	,, ..	0·8	126	1	..	..	0·8
33MI ..	,, ..	0·9	248	6	..	..	2·4
34MAI ..	,, ..	1·0	134	3	..	..	2·2
35MI ..	,, ..	1·0	267	9	..	..	3·4
36WAI ..	,, ..	1·1	220	2	..	..	0·9
37MI ..	,, ..	1·3	121	19	..	..	15·7
38MAI ..	,, ..	1·4	667	35	..	..	5·2
39MI ..	Eyed ova ..	2·0	919	13	..	..	1·4
40MAI ..	,, ..	2·0	110	9	..	..	8·2
41MI ..	,, ..	2·1	282	8	..	..	2·8
42MI ..	,, ..	2·2	767	7	3	..	1·3
43MAI ..	,, ..	2·3	819	320	10	..	40·3
44MI ..	,, ..	2·3	903	35	13	..	5·3
45WAI ..	,, ..	2·4	276	..	..	..	0·0
46MI ..	,, ..	2·4	346	8	..	..	2·3
47MI ..	,, ..	2·5	375	5	..	..	1·3
48WAI ..	,, ..	2·6	271	11	..	..	4·1
49MAI ..	,, ..	2·6	459	11	1	..	2·6
		Per Cent.					
50MI ..	Alevins ..	28	379	223	10	2	62·0
51MI ..	,, ..	39	863	30	3	..	3·8
52MAI ..	,, ..	55	483	35	16	..	10·6
53MI ..	,, ..	62	779	6	..	7	1·7
54MI ..	,, ..	81	168	1	..	1	1·2
55MI ..	,, ..	81	470	8	10	3	4·5
56MI ..	,, ..	84	295	20	20	10	16·9
			Series D.				
57 ..	Pre-eyed ova ..	0·6	160	2	..	..	1·3
58 ..	,, ..	0·7	167	..	..	..	0·0
59 ..	,, ..	0·9	163	3	..	..	1·8
60 ..	,, ..	0·9	232	1	..	..	0·4
61 ..	,, ..	1·0	209	61	..	..	29·2
62 ..	,, ..	1·0	147	13	..	..	8·8
63 ..	,, ..	1·1	146	1	..	..	0·7
64 ..	,, ..	1·4	170	12	..	..	7·1
			Series E.				
65 ..	Eyed ova ..	2·4	1,372	22	..	..	1·6
		Per Cent.					
66 ..	Alevins ..	32	1,393	13	..	..	0·9
67 ..	,, ..	71	1,717	44	..	2	2·7
68 ..	,, ..	86	803	5	..	1	0·7

APPENDIX G.

River-system: Waihou (or Thames).

Stream: WAIHOU. Length, 102 miles; length of area sampled, 12 miles.
Localities inspected: Source to Okoroire, Te Poi, Okauia, Gordon, Manawaru, Te Aroha, and Paeroa.
Localities sampled: Source to Okoroire.
Surrounding Country: Pastoral downs to pastoral plains.
Geological Features: Rhyolite bed-rock occasionally occurs.
Width of Stream: 12 ft. to 25 ft.
Number of Channels: One only.
Freshes: Very slight and infrequent. *Floods:* Nil.
Flow and Depth: Swift rippled and smooth water of 1 ft. to 3 ft. with short pools to 6 ft.
Material comprising Bed: Rhyolite sand to gravel of 2½ in. with some pumice.
Bed: Very stable and cemented, with rich diatom growth.
Banks: Stable, with shrub growth.
Vegetation: Bed-rooted, in patches; marginal, water-cress frequently.
Stock: Rainbow trout, predominantly small, in great abundance.
Samples collected: 18 (1936, 5; 1937, 13).
Month of Collection of Pre-eyed Samples: July (5).
Months of Collection of Eyed Samples: July (5), August (1).
Months of Collection of Alevin Samples: July (3), August (4).
Proportion of Redds contiguous: 15/18 (but some fish still spawning).

With samples from the Waihou itself in Series A of Table IX are included three from the Waimakariri and one from the Oraka. Series B comprises twenty-four samples from the Omahine and Raparapa. Of these, four came from contiguous redds at a time when some fish were still spawning. Nine samples were taken in 1936 and fifteen in 1937. The July collections comprised five pre-eyed, seven eyed, and four alevin samples; the August collections two eyed and six alevin samples.

Table IX.

Waihou, Waimakariri, Oraka .. .. Waihou system, Series A.
Omohine, Raparapa .. .. .. ,, Series B.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series A.				
1 ..	Pre-eyed ova ..	0·7	310	5	..	..	1·6
2 ..	,, ..	0·8	242	4	..	..	1·6
3 ..	,, ..	0·9	94	2	..	..	2·1
4 ..	,, ..	1·0	438	10	..	..	2·3
5 ..	,, ..	1·3	83	3	..	..	3·6
6 ..	Eyed ova ..	1·7	292	22	2	..	8·2
7 ..	,, ..	1·8	1,081	18	..	..	1·7
8W ..	,, ..	1·8	492	144	31	..	35·6
9 ..	,, ..	2·1	162	11	..	..	6·8
10W ..	,, ..	2·1	216	12	..	..	5·6
11 ..	,, ..	2·3	242	12	..	..	5·0
12 ..	,, ..	2·3	546	49	..	..	9·0
13 ..	,, ..	2·4	327	29	..	..	8·9
14W ..	,, ..	2·4	426	6	..	..	1·4
		Per Cent.					
15 ..	Alevins ..	45	243	21	..	..	8·6
16 ..	,, ..	63	295	56	1	..	19·3
17 ..	,, ..	65	192	11	..	..	5·7
18 ..	,, ..	69	388	53	7	..	15·5
19O ..	,, ..	73	158	2	..	..	1·3
20 ..	,, ..	75	257	5	..	..	1·9
21 ..	,, ..	76	242	15	1	..	6·6
22 ..	,, ..	83	525	103	..	2	20·0

TABLE IX—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series B.				
23O ..	Pre-eyed ova ..	0·7	2,875	41	..	..	1·4
24O ..	,, ..	1·1	1,546	27	..	..	1·7
25O ..	,, ..	1·2	1,908	73	..	..	3·8
26R ..	,, ..	1·2	1,666	48	..	..	2·9
27R ..	,, ..	1·3	887	67	..	..	7·6
28O ..	Eyed ova ..	1·5	410	13	..	..	3·2
29R ..	,, ..	1·5	1,222	43	..	..	3·5
30R ..	,, ..	1·6	2,178	81	..	..	3·7
31O ..	,, ..	1·7	2,654	67	..	..	2·5
32R ..	,, ..	1·9	634	28	3	..	4·9
33R ..	,, ..	2·0	1,052	22	..	..	2·1
34R ..	,, ..	2·2	547	23	..	..	4·2
35R ..	,, ..	2·3	377	5	..	..	1·3
36R ..	,, ..	2·5	603	44	..	..	7·3
		Per Cent.					
37R ..	Alevins ..	36	1,175	124	10	..	11·4
38O ..	,, ..	41	573	25	..	..	4·4
39R ..	,, ..	47	512	20	..	1	4·1
40O ..	,, ..	50	262	13	..	..	5·0
41R ..	,, ..	57	618	40	..	..	6·5
42R ..	,, ..	59	932	19	..	3	2·4
43O ..	,, ..	80	564	39	..	..	6·9
44R ..	,, ..	89	2,425	52	..	1	2·2
45R ..	,, ..	94	249	8	..	..	3·2
46O ..	,, ..	98	201	5	1	..	3·0

APPENDIX H.

RIVER-SYSTEM: WAIKATO.

Stream: WAIKATO.

The summary of principal characteristics hitherto employed in appendices is not used in the case of the Waikato itself because, in it, major spawning-areas were not located. The origin of the samples comprising Series A of Table X is shown by the use of the following index letters: A = L. Arapuni tributary entering below Waipapa; B = backwater of Waikato and seepage stream; W= Waitete; H = Hui Creek; C = creek opposite Little Waipa mouth; P = lower Pokaiwhenua tributary.

In Series B the one sample which is not from the Little Waipa is indicated by the initial letter of its stream of origin—the Otarnaroa.

TABLE X.

Sundry pumice—rhyolite tributaries .. Waikato system, Series A.
Little Waipa and Otarnaroa .. .. ,, Series B.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series A.				
1C ..	Pre-eyed ova ..	0·7	111	1	..	..	0·9
2C ..	,, ..	1·3	1,662	244	..	..	14·7
3C ..	,, ..	1·4	335	20	..	..	6·0
4P ..	Eyed ova ..	1·6	198	189	1	..	96·0
5C ..	,, ..	2·0	1,209	298	7	..	25·2
6H ..	,, ..	2·4	1,739	100	2	.	5·9
		Per Cent.					
7W ..	Alevins ..	34	167	98	3	1	61·1
8C ..	,, ..	62	479	..	158	2	33·4
9B ..	,, ..	82	140	16	..	..	11·4
10A ..	,, ..	98	509	389	8	8	77·8

TABLE X—*continued.*

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series B.				
11 ..	Pre-eyed ova ..	0·5	111	..	..	..	0·0
12 ..	,, ..	0·5	422	9	..	..	2·1
13 ..	,, ..	0·9	797	132	..	..	16·6
14 ..	,, ..	1·0	1,379	53	..	..	3·8
15 ..	,, ..	1·1	893	61	..	..	6·8
16 ..	Eyed ova ..	1·5	364	9	..	..	2·5
17 ..	,, ..	2·0	2,243	170	4	..	7·8
18 ..	,, ..	2·1	364	16	1	..	4·7
19 ..	,, ..	2·2	1,854	192	15	..	11·1
		Per Cent.					
200 ..	Alevins ..	35	115	26	..	..	22·6
21 ..	,, ..	35	1,590	576	536	8	70·4
22 ..	,, ..	39	267	7	1	79	32·6
23 ..	,, ..	40	370	10	..	..	2·7
24 ..	,, ..	59	975	87	86	13	19·1
25 ..	,, ..	82	104	37	..	2	37·5

RIVER-SYSTEM: WAIKATO SUB-SYSTEM: WAIPA.

Stream: WAIPA. Length, 100 miles; length of area sampled, 5 miles.
Source: Mounts Rangitoto and Ranganui.
Locality sampled: The 5 miles below entrance of Waimahora.
Surrounding Country: Narrow rich pastoral floor of valley between low partially deforested hills.
Geological Factors: Predominantly hard sedimentary bed-rock.
Width of Stream: 30 ft. to 70 ft. *Width of Flood-bed:* 20 yards to 60 yards.
Number of Channels: One.
Freshes: Frequent. *Floods:* Not uncommon.
Flow and Depth: Much rippled water to 2½ ft.; frequent pools to 4½ ft. and sometimes 10 ft.
Material comprising Bed: Heavy rounded gravel—much 2 in. to 6 in.; pools often margined with bed-rock.
Bed: Commonly fairly stable with moderate to good diatom growth.
Banks: Commonly 1 ft. to 4 ft. stable with vegetation—elsewhere sloping shingle or sometimes eroded coarse alluvium.
Vegetation: Bed-rooted, nil; marginal, nil.
Stock: Both brown and rainbow trout commonly less than 3 lb.
Samples collected: 20 (1936, 3; 1937, 17).
Month of Collection of Pre-eyed Samples: July (9).
Months of Collection of Eyed Samples: July (5), August (1).
Months of Collection of Alevin Samples: Selected in July and August.
Proportion of Redds contiguous: 8/20 (but fish still spawning).

Of samples from other tributaries, two of nine from the Mangatutu, and two of ten Mangaokewa ones came from contiguous redds. Samples from the Tauraroa are shown with those from the Waipa in Series C1 of Table XI and are distinguished by use of the initial letter of the former name.

TABLE XI.

Waipa sub-system .. .. .. Waikato system, Series C.
Waipa and Tauraroa .. .. .. ,, Series C1.
Mangatutu .. .. ,, Series C2.
Mangaokewa .. .. .. ,, Series C3.

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
			Series C1.				
26 ..	Pre-eyed ova ..	0·5	315	4	..	..	1·3
27 ..	,, ..	0·5	726	13	..	..	1·8
28 ..	,, ..	0·6	1,725	442	..	..	25·6
29 ..	,, ..	0·7	308	168	..	..	54·5
30T ..	,, ..	0·7	711	..	..	..	0·0
31 ..	,, ..	0·8	645	13	..	..	2·0
32 ..	,, ..	0·8	124	5	..	..	4·0
33T ..	,, ..	0·8	736	13	..	..	1·8
34 ..	,, ..	0·9	691	19	..	..	2·7
35 ..	,, ..	1·1	1,093	24	..	..	2·2
36 ..	,, ..	1·3	303	6	..	..	2·0
37 ..	Eyed ova ..	1·3	1,271	54	..	..	4·2
38T ..	,, ..	1·4	1,355	31	..	..	2·3
39 ..	,, ..	1·7	906	61	..	..	6·7
40T ..	,, ..	1·9	1,593	29	1	..	1·9
41 ..	,, ..	2·0	171	8	1	..	5·3
42T ..	,, ..	2·1	1,436	51	1	..	3·6
43T ..	,, ..	2·1	930	34	..	..	3·7
44 ..	,, ..	2·2	683	12	1	..	1·9
45 ..	,, ..	2·3	900	21	..	..	2·3
46 ..	,, ..	2·7	689	25	..	..	3·6
		Per Cent.					
47 ..	Alevins ..	33	363	230	68	..	82·1
48 ..	,, ..	36	342	3	1	..	1·2
49 ..	,, ..	65	358	7	1	2	2·8
50 ..	,, ..	66	284	9	7	1	6·0
51 ..	,, ..	87	414	2	..	..	0·5
			Series C2.				
52 ..	Pre-eyed ova ..	1·1	369	177	..	..	48·0
53 ..	,, ..	1·4	1,793	12	..	..	0·7
54 ..	Eyed ova ..	1·5	1,303	30	..	..	2·3
55 ..	,, ..	1·9	2,090	49	..	..	2·3
56 ..	,, ..	2·0	1,337	18	1	..	1·4
57 ..	,, ..	2·2	1,087	31	1	..	2·9
58 ..	,, ..	2·3	2,432	39	1	..	1·6
		Per Cent.					
59 ..	Alevins ..	49	959	57	6	..	6·6
60 ..	,, ..	52	281	14	..	..	5·0
			Series C3.				
61 ..	Pre-eyed ova ..	0·7	777	12	..	..	1·5
62 ..	,, ..	?	467	467	..	..	100·0
63 ..	,, ..	1·0	356	5	..	..	1·4
64 ..	,, ..	1·2	818	9	..	..	1·1
65 ..	Eyed ova ..	1·6	363	5	..	..	1·4
66 ..	,, ..	1·8	956	10	..	..	1·0
67 ..	,, ..	2·0	668	8	..	..	1·2
68 ..	,, ..	2·2	348	12	..	..	3·4
69 ..	,, ..	2·3	538	1	1	..	0·4
70 ..	,, ..	2·4	750	11	..	..	1·5

APPENDIX I.

River-system: Awakino.

Stream: AWAKINO. Length, 38 miles; length of area sampled, 5 miles.
Source: Coastal hills.
Localities sampled: 22 and 27 miles from mouth.
Surrounding Country: Upper 18 miles through very narrow valley between steep bush-clad slopes deforested in parts.
Geological Features: Bed-rock, which in parts bounds and beds the stream, is of soft sedimentary kinds.
Width of Stream: 20 ft. to 50 ft. *Width of Flood-bed:* Nil.
Number of Channels: One.
Freshes: Frequent. *Floods:* Not common.
Flow and Depth: Two-thirds rippled gravel reaches to 2 ft.; one-third rock-bound pools.
Materials comprising Bed: Soft sedimentary gravel to 4 in. with some harder gravel—much embedded; bed-rock less commonly.
Bed: Stable to very stable with good diatom covering.
Banks: Everywhere stable—often to 10 ft., steep, with vegetation; less commonly to 2 ft. through grassed flats.
Vegetation: Bed-rooted, nil; marginal, narrow belts in places.
Stock: Rainbow trout only—mostly less than 3 lb.
Samples collected: 9 (1936, 4; 1937, 5).
Month of Collection: August (all samples).
Proportion of Redds contiguous: 2/9.

Included in Table XII with the samples from the Awakino are two from Stoney Creek, a small and relatively unstable hill tributary. The gravel in the tributary is similar in character to that of the main stream.

Table XII.—Awakino and Stoney Creek (Awakino System).

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead, per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
1S ..	Pre-eyed ova ..	0·8	342	7	..	..	2·0
2 ..	,, ..	1·3	1,149	18	..	..	1·6
3S ..	Eyed ova ..	1·6	576	17	..	..	3·0
4 ..	,, ..	1·9	753	21	..	..	2·8
5 ..	,, ..	2·4	779	30	..	..	3·9
		Per Cent.					
6 ..	Alevins ..	28	1,096	59	15	2	6·9
7 ..	,, ..	37	984	15	..	..	1·5
8 ..	,, ..	70	1,118	221	157	..	33·8
9 ..	,, ..	80	906	8	..	..	0·9

APPENDIX J.

TABLE XIII.—WANGANUI AND TRIBUTARIES (WANGANUI SYSTEM).

Index No.	Stage.	Development Point.	Sample.	Analysis of Dead.			Total Dead. per Centum.
				Pre-eyed Ova.	Eyed Ova.	Alevins.	
1P ..	Pre-eyed ova ..	1·3	324	3	..	..	0·9
2 ..	,, ..	1·3	343	7	..	..	2·0
3 ..	Eyed ova ..	1·4	787	8	..	..	1·0
4 ..	,, ..	1·5	182	2	..	..	1·1
5 ..	,, ..	1·6	431	11	..	..	2·6
6O ..	,, ..	1·6	888	12	..	..	1·4
7 ..	,, ..	1·6	446	199	..	..	44·6
8 ..	,, ..	1·7	147	3	..	..	2·0
9 ..	,, ..	1·9	245	13	..	..	5·3
10 ..	,, ..	2·1	116	8	..	..	6·9
11 ..	,, ..	2·3	900	15	..	..	1·7
12W ..	,, ..	2·3	328	7	..	..	2·1
13 ..	,, ..	2·4	1,536	49	..	..	3·2

APPENDIX K.

QUANTITATIVE STUDIES.

THE KAKANUI SYSTEM.

IN 1936 the estimation was attempted of the total contents of spawning redds in the Kakanui River system from the Kakanui Gorge down to the short tidal section. Approximately twenty miles of river, having an average width of about 40 ft., was examined. Little is known of the possibilities of fish spawning in the gorge and hill sections of this stream. Examination of the lower mile of the gorge did not disclose the presence of any redds. The general character of the country above was unpromising.

All redds observed were counted, and the collection of the contents of every twentieth was attempted. It was found subsequently that many of these apparently single redds were actually small groups of superimposed redds, but the basis of sampling was not thereby invalidated. Where obvious groups of redds were too closely massed to enable the single ones to be counted, the total area of bed dug was measured and a sample was taken from a typical square yard.

In all, 326 redds were counted and 49·7 square yards of congested spawning-area were measured. The sixteen sample redds dug (see Table XVIII) yielded 23,461 specimens. Three square-yard plots from congested areas yielded 3,402 specimens (798, 1,182, and 1,422). The average numbers of specimens were, therefore, per redd, 1,466 specimens; and, per square yard, 1,134. On this basis, the estimated total contents of spawning-areas encountered were $1,466 \times 326 + 1,134 \times 49{\cdot}7$ = approximately 534,000. Fish had finished spawning before this survey was made. The bulk of the specimens obtained were then in the eyed stage and many were well-developed alevins. An inspection made subsequently, when fry had emerged from most redds, showed the contours of redds to be still unchanged by flood action.

For the following reasons the estimate of the number of specimens in redds is likely to be a conservative one:—

(1) The complete water-system was not examined.

(2) Inspection of certain reaches was made when overcast skies and wind severely limited visibility.

(3) Diatom regeneration and any earlier flood action reduced the chances of older redds being seen. Local informants stated that fish had spawned weeks earlier at several points, where redds were not subsequently observed.

(4) The estimate is based on numbers of specimens recovered from sample redds, and it is known that recovery was not always complete.

Of the specimens recovered from sample redds and plots, 97·1 per cent. were alive. On this basis there were not less than half a million live specimens present, most of which had passed through the most vulnerable stage and which were not subsequently affected adversely by superimposition or by flood action.

The Waihou System.

In 1936, in the Omohine Stream, fifty-six apparent redds (some of which were superimposed) were counted in the lowest mile of water, where the bulk of its stock of rainbow trout spawns. An examination of four typical redds there showed them to contain from 410 to 2,875 specimens each, with an average content of 1,961 ova. On this basis, specimens then present in redds observed would have numbered about 110,000. A proportion of the stock was still spawning at the time of sampling.

In 1937 redds of rainbow trout were counted in the lowest three and a half miles (the bulk of the gravel-bedded portion) of the Raparapa Stream. Apparently single redds, some of which were found to contain two samples, numbered 121. Eight typical redds contained ten samples and yielded from 512 to 2,425 specimens, with an average of 1,098 each. On this basis, redds found are estimated to have contained about 134,000 specimens.

The Waikato System.

In 1936, in the small Waipa sub-system tributary, the Tauraroa, sixty-one apparent redds were counted in the two and a quarter most suitable miles of water, at a time when many brown and rainbow trout were still spawning there. Six typical ones yielded from 711 to 1,593 specimens, with an average of 1,127. On this basis the deposition at that time in this tributary would have exceeded 68,000 specimens.

Examination was made in 1937 of sections of the Mangatutu Stream—a Punui branch tributary of the Waipa sub-system—in which brown and rainbow spawn. Counts of redds were made in two sections of 350 yards and three of 400 yards—the five sections being spaced at intervals of one mile, as measured on the road which follows the course of the stream. The numbers of redds per average 100 yards in the five sample areas were 3·43, 4·25, 4·25, 5·25, and 6·57. Such a uniform usage of stream-bed for so considerable a distance is very remarkable. The 1,900 yards comprising the five sampling-areas contained 90 redds. On this basis, there were 83·36 redds per linear mile of stream course. Eight typical redds yielded nine samples and contained from 650 to 2,432 specimens each, with an average of 1,456. Estimated deposition per average mile = 1,456 × 83·36—that is, approximately 121,000 specimens. Apart from other portions offering less suitable spawning conditions, there was from seven to ten miles of water in which a deposition similar to that in the sample areas could be expected.

The average production per redd counted in the streams just discussed is sometimes greater than the average size of the samples shown in earlier qualitative tables. This is because the production figures are based on counts of redds which, not uncommonly, contained more than one sample. The figures relate to effective depositions over and above any removals which have taken place through superimposition or flood action. Data which follow relate to productions of ova of different stocks and include whatever proportions are destroyed in either of these ways.

The Waituna System.

In 1936 a trap was maintained in Waituna Creek from 25th April to 6th July. It is known that a few spawners had entered the stream before the trap was installed, that a small proportion of fish spawned before reaching the trap, and that fish were still running very strongly when the trap was removed. Of 1,904 trout trapped, 1,177 were females. The latter totalled 7,367 lb. in weight. A sample of fifteen females of varying sizes showed an egg-production of 781 ova per average pound of weight. On this basis, females trapped are alone estimated to have produced 5,750,000 eggs.

The Waiau System.

Streams trapped in the Waiau-system waters by the Southland Acclimatization Society in the ten years preceding 1936 include the Eglinton, Upukororo, Mararoa, and Wairaki Rivers, and Henry Creek. Different streams or groups of streams were trapped in different years. Annual reports of this body for the year immediately succeeding each operation show that the following collections of eggs have been made: Eglinton, 1934 = 4,043,000; Upukerora, 1935 = 1,907,000; Mararoa, 1927 = 2,470,000; Wairaki, 1930 = 1,320,000; Henry, 1932 = 380,000. These are maximum collections from each stream in any year of the ten. In no case, however, does the figure represent the total production of ova in a stream. In no case was a trap maintained for the duration of the

spawning season, and even during trapping periods considerable escapages of fish commonly occur. The production of eggs by fish already in the streams above the trap-sites is not shown, nor is the production by fish which spawn below trap-sites taken into account. Further, of fish trapped and available for stripping, a proportion only, although usually a major proportion, are stripped. Finally, these figures of eggs stripped from fish do not include the quantity of eggs normally left in them, when artificial expression must be practised without killing the producers. In 1935, when there was less flood interference than usual with trapping operations, it was reported (*vide* 1936 annual report) that ova taken from fish trapped in the Eglinton and Upukororo alone numbered 5,648,000. Further, it is stated that, of fish actually trapped, only a proportion were stripped, and the production of fish penned is estimated at about 11,000,000 eggs. In that year a proportion only, and possibly not a very large one, of trout entering these two streams to spawn was trapped.

In view of the foregoing facts and of the known existence of extensive spawning-areas in other streams sometimes trapped, of very extensive spawning-areas in the Waiau itself and in its Orawia sub-system, and of smaller areas in minor tributaries, it seems very improbable that ova taken for hatchery purposes constitute any very considerable part of the total production. Further, it becomes clear that collections made from natural redds in both the Waiau and Waituna systems and used for qualitative studies in this paper constitute but fractional parts of the total contents of natural redds.

Discussion.

Lest discussion of data relating to extents of effective depositions and productions of ova from a few waters only should exaggerate the significance of certain of them as nursery areas, some further comment seems necessary. The streams in which counts of redds were attempted are relatively unimportant both as nursery and angling waters. Of them the Kakanui alone is well known, but its reputation is a very local one and is only merited because lack of other good waters in the vicinity focused attention on it. The Omohine, Raparapa, Tauraroa, and Mangatutu are known only locally. As nursery areas these four, while locally useful, have little significance by broader New Zealand standards.

Waituna Creek is, for its size, an exceptionally productive nursery area. In itself it offers no angling, but with lesser feeders it furnishes the stock which provides a limited amount of angling at the outlet of Waituna Lagoon.

The Waiau system is one of the very few highly productive major water-systems in New Zealand. It is remarkable in that it comprises so many good spawning-streams, although, individually, few such streams are exceptional by New Zealand standards.

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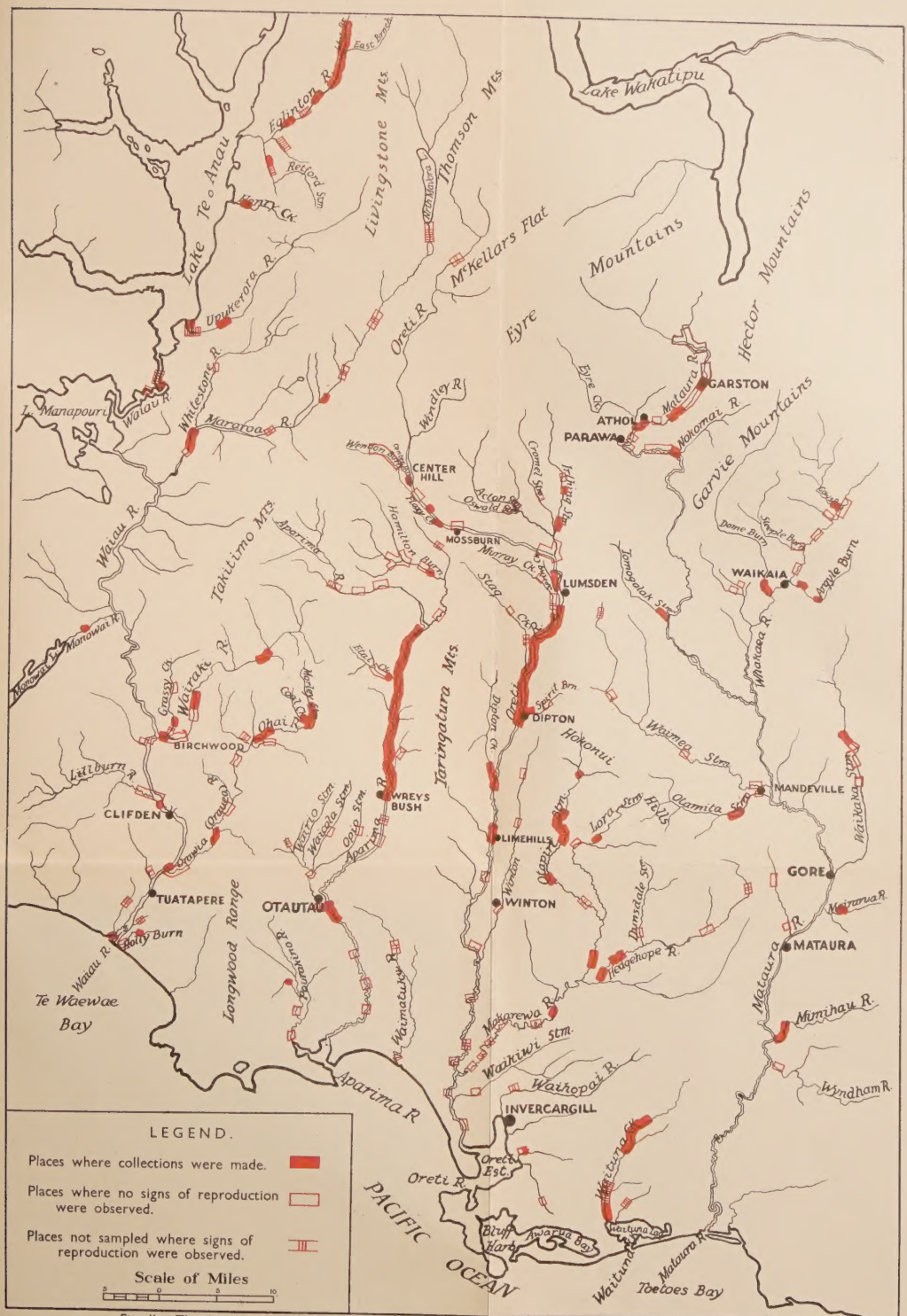
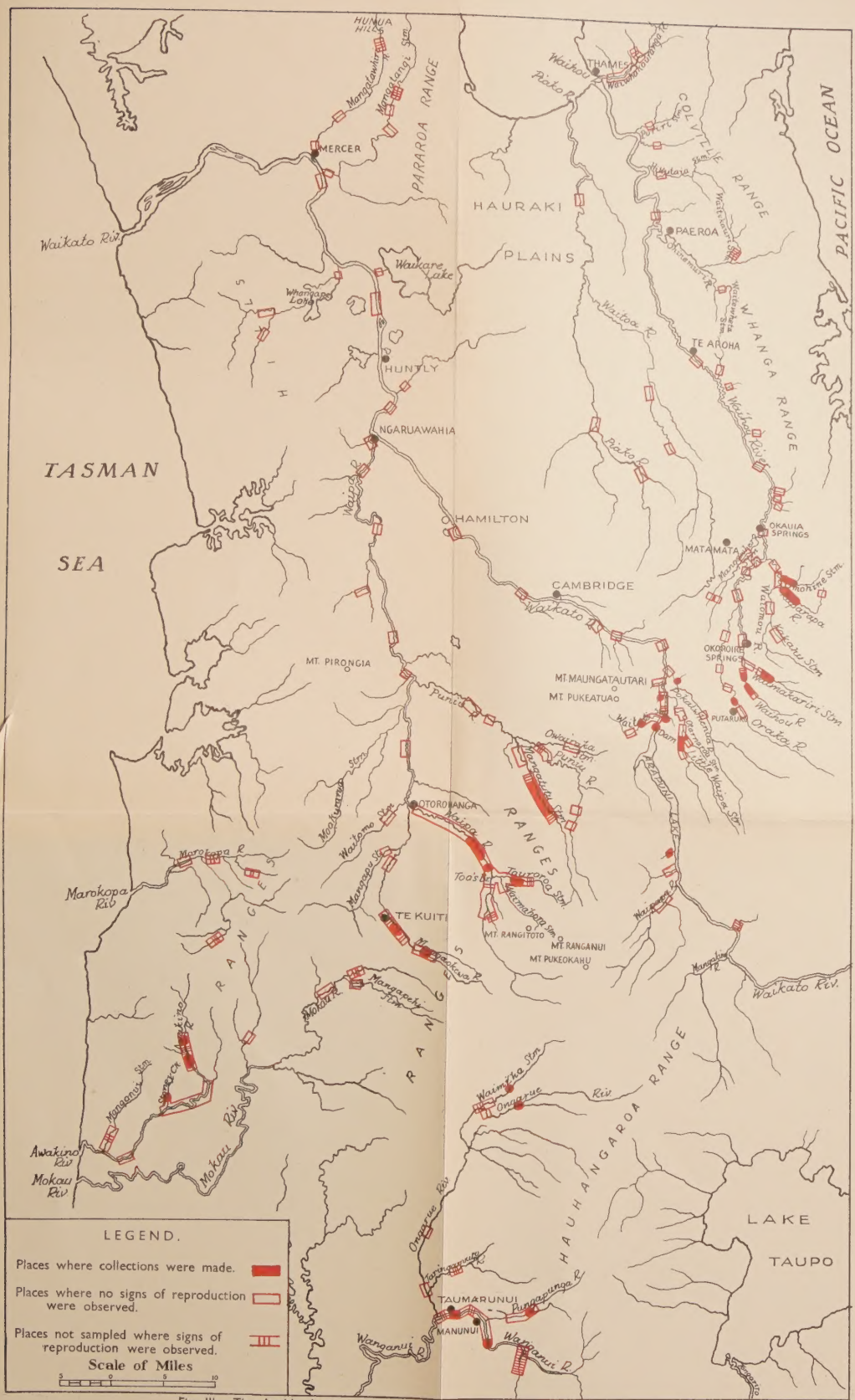


Fig. 11.—The Southland and South Otago river systems, showing in red areas examined and sampled.


HUNUA HILLS
Mangatawhiri Stm
Mangatangi Stm
PARAROA RANGE
MERCER
Waikato Riv
Whangape Lake
Waikare Lake
HUNTLY
NGARUAWAHIA
TASMAN SEA
Waipa R
HAMILTON
CAMBRIDGE
Waikato R
MT. PIRONGIA
Punui R
Owairaka Stm
Mangakotuku Stm
Mangakotuku Stm
Waiaro Stm
Waiaro Stm
Waiaro Stm
Waiaro R
Waiaro Stm
Waiaro Stm
OTOROHANGA
Waiaro R
RANGES
Toa's R
Tauroa Stm
Marokopa R
Marokopa Riv
Waitomo Stm
Waitomo Stm
Waitomo Stm
TE KUITI
Mangaokewa R
Mangaokewa R
MT. RANGITOTO
MT. RANGANUI
MT. PUKEOKAHU
Mokau R
Mangaotaki Stm
Mangaotaki Stm
Mangaotaki Stm
Mangaotaki Stm
Awakino Riv
Mokau Riv
Mokau Riv
Waimiha Stm
Ongarue Riv
Ongarue Riv
Ongarue Riv
Tongariro R
TAUMARUNUI
Pungapunga R
MANUNUI
Wanganui R
Wanganui R
Wanganui R
HAUHANGAROA RANGE
LAKE TAUPO
Waikato Riv
Mangaiti R
Waitahanui R
Waitahanui R
Waitahanui